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THE HARAHAN BRIDGE AT MEMPHIS, TENNESSEE.*

BY

RALPH MODJESKI, D.Eng.,

Consulting Engineer, Chicago, Ill.
Member of the Institute.

THE great cantilever bridge crossing the Mississippi at Memphis, Tenn., known as the Harahan Bridge, is the second bridge erected at that point and is an important addition to the long list of American cantilever bridges. The bridge was authorized by act of Congress, August 23, 1912, and built by the Arkansas and Memphis Railway Bridge Terminal Company for the joint ownership and use of the Rock Island Lines, the St. Louis, Iron Mountain and Southern Railway, and the St. Louis Southwestern Railway.

The first steel was erected on Pier 1, April 7, 1915. Considerable delay in erection of the river spans was experienced, owing to the almost unprecedented high stage of the river during the summer months, when a low stage may usually be looked for. This prevented commencement of erection when expected. Later, again, when the erection of spans 3 and 4 was barely commenced, the river rose to a stage of 26.6 feet on December 23, 1915, carrying away the falsework between piers 3 and 4, and some five hundred tons of steel beams, stringers and other material, which had been deposited or assembled on the falsework during the initial stage of erection of this span. In order to insure an early

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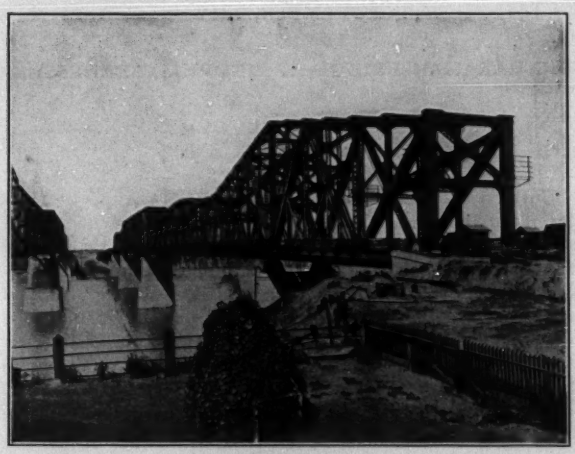
completion of the bridge, a supplemental agreement was entered into between the bridge company and the contractors by which this span would be erected partly without falsework and without waiting for the summer low water. This involved some changes in the plans and the payment of a premium for quick delivery of material. It also became expedient to protect the contractors against loss by high water of such falsework as would still be required for this span. These arrangements permitted the completion of the bridge several months sooner than could have been



The Harahan Bridge at Memphis.

done had the course of waiting for the low water been carried out. The last pin was driven in this span on June 28, 1916. The first train was run over the bridge on July 14, 1916, and the bridge opened to railway traffic on the day following.

GENERAL DESCRIPTION.

The bridge crosses the Mississippi River two hundred feet upstream from, and parallel to, the old bridge now owned by the St. Louis and San Francisco Railroad, and which in this report will be called the Frisco Bridge. The eastern end of both bridges

is within the city limits of Memphis, Tenn., while the western end lands in Crittenden County of the State of Arkansas. At ordinary low water the Mississippi River at this point is about 1900 feet wide between banks, while at bank-full stage it is about 2050 feet wide. At extreme high-water stages the river overflows the low land in Arkansas for several miles inland on the bridge line. This made it necessary to construct a long, open viaduct approach and thus provide a large cross-section to take care of flood waters, as required by the War Department. The Tennessee shore is formed by bluffs on which the city is built. The top of these bluffs is nearly at the same elevation as the bridge deck, so that no long approaches were required at the east end of the bridge. The structure covered by this report consists of two main portions—the main bridge and the Arkansas viaduct. The main bridge comprises from east to west one anchor arm 186 feet 3¾ inches long, one channel span 790 feet 5¼ inches long, one fixed or centre span, 621 feet long, one shore span 604 feet 1½ inches long, and one deck span 345 feet long. These rest on six piers, the easterly one being an anchor pier acting both as an anchorage and as an abutment. The total length of the main bridge, counting between centres of extreme end pins of the spans, is 2548 feet 10½ inches, including a distance of 2 feet between centres of end pins at pier 4. Owing to the proximity to the Frisco Bridge, the river piers were necessarily located exactly opposite those in the Frisco Bridge, but, for reasons explained further in this report, pier 4, which is placed on the west bank of the river, was moved 17 feet towards the river, thus making the shore span shorter than the corresponding span in the Frisco Bridge. Permission to do so was received from the War Department. The main bridge is built to provide a vertical clearance of 75 feet above high water of 1887. This high water corresponds to elevation 215.85 of the U. S. Government gauge or to 33,14 of the Weather Bureau datum. The viaduct is composed of plate girder spans placed on steel towers, which in turn rest on concrete piers. There are twenty 80-foot and nineteen 40-foot spans, making the total length of the viaduct 2360 feet. The total length of the bridge between centres of extreme end bearings is 4912 feet 9½ inches. The superstructure of the main bridge was designed as a four-span cantilever system continuous

over five piers, the deck span being independent. This is a very similar disposition to the one followed in the Frisco Bridge, the difference being: first, that the anchor arm has been made shorter to obviate any reversal of stress in the anchor bars, which will thus always be in tension; and, second, in the length of the suspended spans, which are shorter than in the Frisco Bridge. These two modifications resulted not only in greater economy of material, but also in reducing the difficulties of cantilever erection by reducing the stresses on adjusting devices at the juncture of the suspended spans and the cantilever arms. The shifting of pier four 17 feet toward the river permitted to shorten the suspended spans by 34 feet, and still have the three cantilever arms and the two suspended spans respectively alike. Both the main bridge and the viaduct are double-track structures, two wagon roadways being also provided on brackets outside of the railway deck. The distance centre to centre of tracks is 14 feet. A horizontal clearance of 30 feet and a vertical clearance of 24 feet above base of rail have been provided. The clear width of each wagon roadway is 14 feet.

Starting at the Memphis end on the railway deck, there is an ascending grade on the anchor or easterly span of 1.1 per cent.; the grade then becomes level and remains so over the three main river spans, and becomes 0.6 descending over the deck span and 1.126 per cent. descending over the entire viaduct. The wagon roadways follow the same grades until pier 4 is reached, and then descend with a 3 per cent. grade for a distance of 2030 feet 11 inches, and then continue level until they reach the county road.

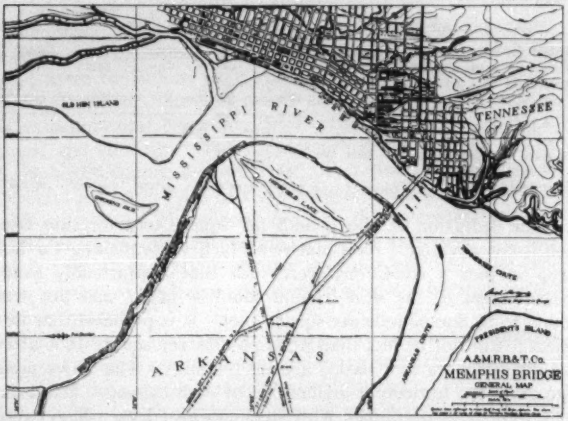
MAIN SUBSTRUCTURE.

Description.

The substructure of the main bridge consists of five piers, numbered consecutively from 1 to 5, pier 1 being placed on the east shore, and one combined anchor pier and abutment. The foundations for piers 1 to 5 were built by sinking caissons by pneumatic process. The foundation for the anchor pier was built in open excavation.

Borings taken before work was commenced revealed very much the same character of materials as were found in the Frisco

Bridge; namely, fine to coarse sand, thin strata of gravel and clay, and a heavy stratum of hard blue clay, which carries the foundations of the Frisco Bridge. No bed rock was found, although the borings extended 200 feet below low-water level. It was therefore decided to sink the foundations to the same stratum of hard blue clay. Experience in the Frisco Bridge with this hard clay taken out of the caissons showed that cubes with two-inch sides, unsupported laterally, could, with one exception, withstand a pressure of at least 100 pounds per square inch, or



Site of the Memphis Bridge, Memphis, Tennessee.

7.2 tons per square foot. It is fair to assume that in case of material supported on all sides the resistance would be greater. Crude experiments made in the caisson working chambers of this bridge by Resident Engineer Case seem to justify that assumption. It was therefore decided that a net pressure of 5 tons per square foot on the clay would be a safe load to impose, and the dimensions of the caissons were determined accordingly. The following table shows the various pressures on the foundations of piers 1 to 5, including full live load:

PRESSURES ON FOUNDATIONS.

Weights in Tons of 2000 Pounds.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
Timber, iron, and concrete in foundations	10110	9330	9470	7800	5190
Concrete in working chamber and shafts	1180	1390	1500	1620	390
Granite masonry concrete backing, except pier 5, which is all concrete	7780	13730	14030	6770	1170
Total weight of pier	19070	24450	25000	16190	6750
Superimposed earth	1810	0	2830	1180	80
Superimposed water to zero gauge	0	2740	1310	0	0
Superstructure dead load	5670	5600	5600	1140	850
Superstructure live load	3870	3900	3900	1910	1070
Total downward pressure	30420	36690	38640	20420	8750
Deduct for water reaction at zero gauge	5310	10920	11250	4950	2090
Deduct for earth displaced	8110	4000	6950	5450	3450
Deduct for skin friction at 400 pounds per square foot	2850 16270	2320 17240	2710 20910	2660 13060	2300 7840
Net weight on foundation	14150	19450	17730	7360	910
Pressure on foundation in tons per square foot	4.4	5.1	4.7	3.1	0.8
Horizontal dimensions of caissons	40′x80′	42′x90′	42′x90′	31′x77′	25′x46′

The deduction of 400 pounds per square foot for skin friction is conservative. As a matter of fact, while making the last drop in pier 4 conditions were such that a practically exact measurement of the skin friction could be taken, and this was found to be 800 pounds per square foot. It is probable that this friction will not be less than 1000 pounds per square foot after the materials are well settled around the piers. The above table also gives the horizontal dimensions of each caisson. The caissons were built of timber with steel cutting edges. They were filled with concrete made of Portland cement mortar and gravel. A small quantity of crushed rock was used in pier 2 when gravel could not be obtained in time. In piers 1, 2, and 3 steel rods were imbedded in the concrete just above the roof of the caisson working chamber to secure additional strength during the first stages of sinking. The general method of sinking was that usually followed in similar cases. The wet "blow out" was used for excavating sand or silty clay, and buckets through air-lock for clay. Elevators were provided in piers 2 and 3 for the use of men in going in and out. The method of sealing the working chamber differed from that used in the Frisco Bridge, and which was generally used at the time that bridge was constructed:

instead of using dry concrete for the entire volume of the chamber, which required men for ramming it in benches, and consumed considerable time, dry concrete was used only to support the edges of the caisson and the crossbeams, under which it was rammed in, and then wet concrete was poured in until the chamber was filled. By that method the time required for sealing a chamber was generally under 48 hours, meaning that the rate of placing concrete in the chamber was about 15 cubic yards an hour. The piers above the caissons, except pier 5, are of granite backed with concrete, except the belting courses and two courses below, which are backed with granite stones of same thickness as the face stones. The coping of these piers is entirely of granite. The bearing surfaces under the steel pedestals have been carefully dressed after the stones were set. The thickest course in the piers is 36 inches. The face stones have a rock or quarry face with projections not exceeding three inches, except the copings, beltings, and starlings. The copings are laid with close joints and are bush-hammered throughout. A four-inch draft line is cut around the lower edge of the belting course and on each side of each nose line. The curved faces of the upstream cutwater and the surfaces over the pointed ends of each pier are fine pointed, with no projections greater than one-half inch; the projecting portion of the lower bed of the coping and belting courses are bush-hammered.

Reinforcing rods 1¼ inches square were used in the concrete backing of the first seven courses, and every seventh course above that, and in the four top concrete-backed courses.

Pier 5 was built entirely of concrete reinforced by steel rods.

PIER 1.—The caisson for this pier was built on shore in place. It was supported on the sand and gravel of the bank. Work was begun on setting the cutting edge on November 23, 1913. The cutting edge was placed 6 inches nearer shore than the desired final position, to provide for the crowding effect of the bank. The caisson was lowered 20 feet, of which 5 feet were below the level of the water, before the air-pressure was applied. Its final position was correct, showing that the 6-inch allowance for crowding was right. The upper eight feet of the crib were of light construction and built of 3-inch vertical planking to act as a form for the concrete. Compressed air and water for sinking were supplied from the floating compressor plant moored near by.

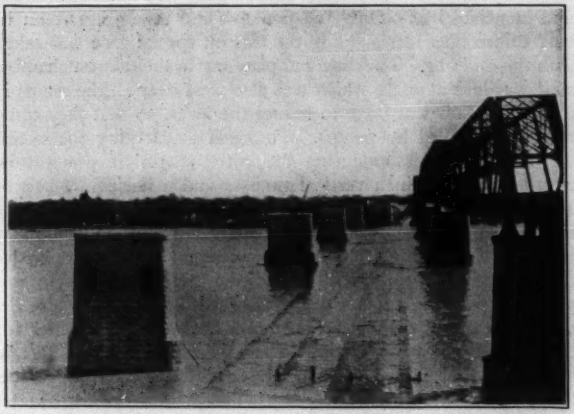
Arkansas and Memphis Railway Bridge and Terminal Company. The Memphis Bridge—General elevation and plan.

PIER 2.—This pier is located in the deepest portion of the river, and because of the great depth of water at this place precautions had to be taken which were considered unnecessary for the other piers. To protect the river bottom from scouring before the landing of the caisson, and also after the work is done, a willow mat 200 feet wide and 300 feet long was sunk at the site of this pier, the long dimension being parallel with the stream and the mat placed so that it extends 200 feet upstream and 100 feet downstream from the centre line of the bridge. The caisson for this pier, as well as for pier 3, was built on a floating pontoon and launched by flooding the pontoon and separating it on its long centre line. In building the caisson special care was taken with the caulking. The diagonal planking in the caisson chamber roof was laid in pitch, which was also used over all the seams in the roof. This was done to reduce the leaks, so that they could easily be handled by pumps. To assist in carrying the excess weight of the caisson during the initial stages of penetration, 24 12-inch by 12-inch vertical timbers and a horizontal belt of 12-inch by 12-inch timbers were bolted to the caisson walls on the outside and just above the caisson chamber. These timbers increased the sinking friction of the caisson sufficiently to enable the excess weight to be easily handled. Before the caisson was placed in position a quantity of sacks filled with sand were deposited on top of the mat so as to reduce the depth of water for the purpose of easier landing of the caisson. About 6 feet in height was thus gained, reducing the depth of water from 51 feet to 45 feet at the time of landing. The greatest head of water during compressed-air work occurred in this pier. It reached 107 feet during the sealing of the working chamber, while the air-pressure was 48 pounds per square inch.

PIER 3.—A small amount of sand sacks were used to level up the river bottom before the caisson was landed. The depth of water at the time of landing was 30 feet. The mat and riprap placed during the construction of the Frisco pier were found over the downstream half of the caisson.

PIER 4.—The caisson for this pier was built in place. The cutting edge was located 18 inches toward shore to compensate for the crowding effect of the bank. The river side of the caisson was supported during construction by a series of boxes

filled with sand and sunk about 8 feet into the silt before the cutting edge was assembled. The caisson was carefully lowered and all necessary precautions taken for keeping it level. In spite of that, the plane of the cutting edge developed a warp of 2 inches before sufficient friction on the sides was attained and sufficient air-pressure applied to assist in lowering the caisson. The air plant for this caisson, as well as for caisson 5, was located 400 feet inshore on an old dike above ordinary high water. The allowance of 18 inches for the crowding effect of the bank proved



General view of completed piers, looking east.

to be too great, and it was with considerable difficulty that the caisson was finally brought to within 3 inches of its true position. After the cutting edge reached a depth of 65.5 feet below low water, or elevation 116.1, the excavation was carried down 3 feet below the cutting edge to a stratum of rock a few inches in thickness overlying the hard blue clay.

PIER 5.—The caisson was built in place. The material traversed was almost entirely sand, very little being removed through the bucket locks. On the morning of April 9 a deplorable accident occurred in which 9 men lost their lives. The men of the gang going in to relieve the crew in the working chamber were over-

come by gas as they were about to lock in, and apparently instantly killed. No definite evidence as to the nature or origin of the gas which had accumulated at the bottom of the main shaft above the lock has been obtained, but the probability is that the accident was due to carbon monoxide formed by the ignition and combustion of methane (CH_4). The men in the working chamber felt no ill effects whatever, and were taken out one by one through the material locks.

ANCHORAGE PIER.—The anchorage pier was built in open excavation 48 feet deep, and, although the clay through which this excavation was made stands well on a vertical face when dry, it was deemed necessary, in view of the considerable depth, to use heavy timbering. The pier was built of concrete faced with granite above the ground line and reinforced by steel rods. The anchor girders were entirely imbedded in the concrete. Wells were left around the anchor bars and filled in later, after the bars had been stretched by subjecting them to a stress, as explained in the chapter on superstructure.

QUANTITIES AND COMPARATIVE UNIT COSTS OF PIERS.

The substructure of the Frisco Bridge was built with the railway company's forces; that of the new bridge was built under contract based on cost and percentage. In both cases, therefore, an accurate account of cost was possible. The design and character of the piers in both bridges are very similar. In both, the piers have been sunk by pneumatic process to about the same elevations, through very similar materials; in both, the face stones are of granite, except that in the Frisco Bridge some limestone facing was used below low water. Because of this similarity it was deemed of interest to prepare unit costs of the various portions of the piers and compare the results with the Frisco Bridge, as given in Morison's report.

VOLUME OF PIERS IN CUBIC FEET.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
Foundation	189,440	192,780	193,725	147,278	93,150
Sinking (actual volume sunk)	243,616	195,642	281,666	182,772	98,088
Masonry	101,986	173,632	180,074	86,282	19,062

UNIT COST IN DOLLARS PER CUBIC FOOT.

	Pier 1	Pier 2	Pier 3	Pier 4 All concrete	Pier 5
Sinking (to actual volume sunk)	0.141	0.310	0.206	0.139	0.109
Foundation (excluding sinking)	0.469	0.759	0.631	0.509	0.494
Foundation (including sinking) (to total volume foundation)	0.649	1.074	0.931	0.682	0.508
Masonry (to total volume shaft)	0.785	0.721	0.757	0.889	0.371
Foundation, sinking, and masonry (to total volume of pier)	0.697	0.906	0.847	0.758	0.568

Morison's report on the old Memphis Bridge gives unit costs, which are on a comparative basis, with the following exceptions: Morison's figures do not include concrete below cutting edge or clay left in chamber above cutting edge, and there are included credits from sale of plant which are not included in the figures for the new bridge. Morison's report also includes the volume of the voids, or wells in the body of the piers. The unit costs which compare with the last line of the former table are as follows:

UNIT COST IN DOLLARS PER CUBIC FOOT OF PIERS OF THE FRISCO BRIDGE.

	Pier 1	Pier 2	Pier 3	Pier 4
Foundation, sinking, and masonry (to total volume of pier)	0.787	0.832	0.999	0.801

MAIN SUPERSTRUCTURE.

Description.

The main superstructure consists of a continuous cantilever system of four spans and one deck span, the lengths of which have been given elsewhere. It carries a double track for railway and two roadways, one on each side, supported on brackets outside of the trusses.

The principal reason for adopting the cantilever system for the river spans was that it enabled the channel span between piers 1 and 2, which is placed over the deepest portion of the river, to be erected without falsework. It would have been extremely hazardous, if not impossible, to erect the 790-foot channel span on falsework. It has been suggested that a fixed or simple span of that length could be erected by cantilever method, but a fixed span of that length has not yet been built, and if built by cantilever method would require a large addition of metal near the ends in the top and bottom cords, to take care of erection stresses. But, even without that addition, a system of fixed spans would weigh considerably more than the one used. It was originally planned to use falsework in all spans except the channel span, but, owing to high water, as already described, the cantilever

arm projecting from pier 3 and the east half of the semi-suspended span between piers 3 and 4 were erected by cantilever method, and only the west half of the latter on falsework.

The superstructure is built partly of carbon steel and partly of a nickel-chrome alloy, known under the name of "Mayari" steel, which is manufactured from Cuban ores containing both nickel and chrome very nearly in right proportions to produce proper bridge material of excellent quality. Nickel steel had been used a short time previous to the construction of this bridge in at least two large bridges where strength of the metal became a source of economy. That alloy was artificially produced by the addition of from three to three and one-half per cent. of nickel and is consequently expensive. Other alloys have also been suggested from time to time for bridgework. In order to receive the benefit of competition and at the same time make a decision possible as to the metal to be used to the best advantage in the structure, the following procedure was adopted: Two distinct designs were worked out in detail, one for carbon steel with only the eye-bars of alloy steel, and one of alloy steel trusses and bottom lateral system and carbon steel floor system, using in both designs unit stresses fifty per cent. higher for alloy tension members and forty per cent. higher for alloy compression members than for carbon steel. The specifications were then prepared in such a way as not to exclude any alloy of nickel and other metals which the manufacturers might desire to submit for use, provided it met the physical requirements, and provided their composition did not contain an excess of injurious elements. Tenders were received on both the carbon and the alloy designs, and the alloy design, costing approximately $68,000 less than the carbon design, was adopted.

Expansion for the trusses was provided on pier 2 by means of specially designed segmental roller bearings. Expansion is also taken care of at the junction of each cantilever arm with the corresponding suspended span and at the shore end of the anchor arm. Anchorage is provided by means of eye-bars attached to steel girders which are placed near the bottom of the anchorage pier. Both the girders and the anchor bars are imbedded in concrete, but wells were left open around the anchor bars until these bars were stretched to correspond to the greatest stress which they will be expected to carry under a moving live

load. This was accomplished by a special device, consisting of bearing blocks and wedges placed on the anchor pier coping. By means of these wedges a requisite tension stress was introduced into the bars, and while they were thus stretched the wells were filled with concrete packed tightly around the bars. In this manner there will be no variation of length in the imbedded anchor bars due to varying loads. The expansion is taken care of by the oscillation of the vertical bars leading from the anchorage to the top chord.

The superstructure was designed to carry a loading of

Arkansas approach viaduct, October 1, 1915.

Cooper's E 55 on both tracks, and in addition thereto 600 pounds per foot of roadway on suspended spans, and 500 pounds on the remainder of the bridge. Members subject to concentrated panel loading were calculated for E 55 locomotives on both tracks with 1120 pounds per lineal foot of the nearest roadway. The stresses in the entire bridge have also been calculated on the assumption of a loading of Cooper's E 75 on each track and 1000 pounds per foot of truss for roadways. Under this "test load," the stresses will not exceed six-tenths of the elastic limit of material in any member, which means that such a loading could be operated over the bridge with perfect safety at moderate speeds.

The weights of metal in the completed superstructure are given in the following table:

	Alloy steel	Carbon Steel	Total	
Anchor arm—				
Chords and end posts	927,370	115,620	1,042,990	
Web system	261,862	842,206	1,104,068	
Railway floor system		364,088	364,088	
Wind and sway bracing		272,473	272,473	
End bearings on pier		312,001	312,001	
Roadway floor system		160,428	160,428	
Railing		43,500	43,500	
	1,189,232	2,110,316		3,299,548
Anchorage material	58,028	181,594		239,622
Three cantilever arms—				
Chords and end posts	3,749,668	37,500	3,787,168	
Web system	644,372	496,494	1,140,866	
Railway floor system		905,712	905,712	
Wind and sway bracing	162,420	402,383	564,803	
Roadway floor system		402,868	402,868	
Railing		130,800	130,800	
	4,556,460	2,375,757		6,932,217
Suspended and semi-suspended spans—				
Chords and end posts	3,678,332	48,240	3,726,572	
Web system	1,307,833	589,678	1,897,511	
Railway floor system		1,515,848	1,515,848	
Wind and sway bracing	86,390	396,040	482,430	
End bearings on pier 4		58,699	58,699	
Roadway floor system		635,840	635,840	
Expansion devices		57,005	57,005	
Railing		195,800	195,800	
	5,072,555	3,497,150		8,569,705
One fixed span—				
Chords and end posts	4,640,577	53,900	4,694,477	
Web system	1,105,649	762,871	2,868,520	
Railway floor system		1,161,260	1,161,260	
Wind and sway bracing	80,650	539,480	620,130	
End bearings, piers 2 and 3		681,195	681,195	
Roadway floor system		459,601	459,601	
Railing		145,769	145,769	
	6,826,876	3,804,076		10,630,952
One deck span—				
Chords and end posts	327,522	716,873	1,044,395	
Web system		539,700	539,700	
Railway floor system		600,654	600,654	
Wind and sway bracing		200,121	200,121	
End bearings piers 4 and 5		82,110	82,110	
Roadway floor system		301,031	301,031	
Railing		81,000	81,000	
	327,522	2,521,489		2,849,011
Railway guard angles, floor bolts, wire supports, and pier ladders		331,809	331,809	
Total—Main Bridge	18,030,673	14,822,191		32,852,864
Adjusting devices	61,174	351,390		412,564
Grand total—Main bridge	18,091,847	15,173,580		33,265,428

The railway and roadway decks are built of creosoted timber. In view of the considerable depth of water between piers 2 and 3 and the necessity of erecting the fixed span on falsework, it was decided to protect the river bottom by sinking woven willow mats over the entire space between the piers and on a width of 200 feet. Special weaving barges were leased for that purpose, and the mats were woven and sunk in place by means of riprap. It is believed that without this precaution the unusual high water in December, 1915, would have endangered this span very seriously. As it was, great pressure was being exerted against the falsework by the accumulated drift, which caused the span to deflect downstream approximately eight inches. Owing to the fact that the lateral system was completely bolted, no damage was done.

It was intended to proceed with the erection of the cantilever arm and semi-suspended span between piers 3 and 4 as soon as the fixed span was erected. To that end, falsework had been placed between these piers and some steel work assembled on top of the falsework and a gantry traveller built to handle the steel. On December 23, as already described, the falsework between piers 3 and 4 went out, due to high water. It was then decided to complete the channel span between piers 1 and 2 while arrangements were being made for replacing the steel lost with the falsework and modifying the details of the span, so as to adapt it to cantilever erection.

The first train, carrying the officials of the bridge company, ran over the bridge on July 14, 1916, and the bridge was opened for traffic the following day.

ARKANSAS APPROACH VIADUCT.

This viaduct is 2363 feet 11 inches long between centre of end bearings, and consists of an alternating series of 40- and 80-foot plate girders, 40-foot spans forming towers. The piers for the towers are of concrete and built on concrete piles. The steel was manufactured under the writer's standard specifications for bridges of 1911. No other steel was to be used in the viaduct, and, as the work is of a simple nature, these specifications were

deemed sufficient. The weights of steel are given in the following table:

	Carbon steel, pounds
Railway floor	4,824,900
Roadway floor	2,752,440
Towers	4,131,810
Railing, guard angles, and refuge platforms	445,910
Total	12,155,060

The total quantities of the principal materials in the main bridge and approaches are as follows: Timber in foundation, 3270 M.B.M.; concrete in piers and foundations, 43,000 cubic yards; granite masonry in piers, 9467 cubic yards; steel in superstructure, 45,420,488 pounds; creosoted timber in railway and roadway decks, 2090 M.B.M.

The Liberty Motor. ANON. (*Aerial Age*, vol. vi, No. 2, p. 53, September 24, 1917.)—One of the first problems which confronted the War Department and the Aircraft Production Board after the declaration of hostilities was to produce quickly a dependable aviation motor. Two courses were open. One was to encourage manufacturers to develop their own types; the other to bring the best of all types together and develop them. The necessity for speed and quantity production resulted in the choice of the latter course. By the inspiring coöperation of consulting engineers and motor manufacturers, who gave up trade secrets under the emergency of war needs, a new motor, designated by the Signal Service as the "liberty motor," has been developed for the use of the United States air service, and is the country's main reliance for the rapid production of this important component of high-powered battle planes.

In power, speed, service ability, and minimum weight the new engine invites comparison with the best the European war has produced. One of the chief rules adopted at the beginning of the designing work was that no engineer should be permitted to introduce construction which had not been tried out: there was no time for theorizing. The new engine is successful because it embodies the best thought of engineering experience to date. Not only did consulting engineers of this country furnish ideas, but representatives in the United States of England, France, and Italy contributed to the development of this motor.

While it is not deemed expedient to set forth in detail the satisfactory performances and the mechanics of the new motor, it may be said that standardization is a chief factor in the development of the

Government's motor. Cylinders, pistons, and every other part have been standardized. They may be produced rapidly and economically by a great many factories operating under Government contracts, and may be rapidly assembled, either by these plants or at a central assembly plant. It should be understood that the "new" motor is not, strictly speaking, an invention. No doubt it has what are in effect new values, but the real result achieved is the combination of the strong points of all the available contrivances of the kind.

Failure of the Carburizing Process. E. F. LAKE. (*Proceedings of the Steel-Treating Research Club of Detroit* (through *Machinery*) (London), vol. x, No. 258, p. 620, September 6, 1917.)—The carburizing or cementation process of adding carbon to iron or ferrous alloys is so ancient that its origin cannot be traced. Metal workers for many centuries made good steel by this process, but they did not know that it was the carbon they added to the metal that gave the desired results. Although any of the new alloy steels, properly worked and heat-treated, will give better results than carburized steel, the latter is still much used in the manufacture of some important machine parts, especially in the automobile industry. Low-carbon steel can be machined more readily than high-carbon steel, and this is one of the reasons why the carburizing process has remained, but the principal argument advanced in favor of carburized parts is that they have a hard outer surface that will resist wear to the greatest degree and a tough centre that will prevent breakage. The value of these properties, however, is less than might be expected.

The steels containing from 0.12 to 0.18 per cent. carbon, which are generally used for carburized parts that contain approximately 1 per cent. carbon in the outer shell, seldom have an elastic limit of more than 40,000 pounds per square inch, and this cannot be increased much more than 5000 pounds by any heat-treatment. If steel with a high enough carbon content to give the best wearing surface is used, the elastic limit can be raised to more than 100,000 pounds per square inch. In the early days of the bicycle, ball and roller bearings first came into general use. Then the cups, cones, races, and even the balls and rollers, were carburized. Manufacturers soon learned, however, that the hard outer shells of the balls would compress against the soft centres and cause them to deform; then the bearings soon failed. Many of the balls would also break and crack between the hard outer shell and the soft core, causing the shell to peel off. When the manufacturers resorted to a high-carbon steel and gave the balls a uniform hardness clear to the centre, they found that a given size ball would carry a much larger load. Later chromium steel was found best for this purpose. At present high-grade ball bearings outwear automobiles, carrying more than twice the load they bore in the bicycle days.

STUDIES IN ACTINOCHEMISTRY.*

BY

HORACE H. CUSTIS, Ph.D.,

George Washington University, Washington, D. C.

INTRODUCTION.

MODERN scientific experiments and theories have established that all organic compounds are the result of chemical change and that light is essential to most forms of organic life. That the chemist is interested in the chemical actions affected by light and radiations of similar character follows as a matter of course.

The action of chlorophyll in plants upon carbon dioxide and water brought about by sunlight or artificial light produces the most marvellous chemical changes, such as formation of sugars, glucosides, starches, essential oils, cellulose, camphor, rubber, alkaloids, gums, resins, etc.

Photography, with all its beauty and manifold applications, would not be possible were it not for the chemical action of light. The physicist, with his well-constructed camera, is able to form a beautiful image, but making that image permanent is a chemical process. Again, the chemist has been called upon to furnish dyes to be used in paints, wall-paper, inks, clothing, etc., that will not fade when exposed to light. The bleaching of cloth by the old process of allowing it to lie on the grass in the sunlight is due to a chemical reaction. The tanning of the skin by sunlight is evidence of a chemical reaction produced by light. Because of the magnitude of the field it has come to be recognized as a distinct branch of chemistry, to which the name "Photochemistry" or "Actinochemistry" has been applied; the latter being preferable because of its more inclusive meaning.

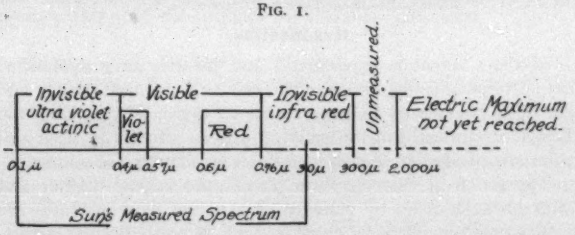
Eder [1] pointed out that the chemical action of light was closely connected with optical absorption: those rays which act chemically on a substance must be absorbed by it. He points out further that, while waves of certain lengths appear to produce specific effects, light of all colors, from extreme violet to ex-

* Communicated by the Author.

[1] "Handbuch der Photographie," 2d ed., 7, 180 (1892); Fr. Bancroft, *Jour. Phys. Chem.*, 12, 209–278 (1908).

treme red, can cause chemical action. The following table (Fig. 1), copied from Bigelow,[2] gives a graphic description of the range of the rays of radiant energy, any of which may be capable of increasing the activity of chemical change. Attention is called particularly to the extremely small proportion of this

FIG. 1.



energy which is capable of affecting our sense of sight, and to the still smaller percentage which is available for use when the ordinary apparatus and conditions employed by chemists are used. This is further indicated by the following table copied from Curtis:[3]

THE LOWER LIMITS OF TRANSPARENCY.

Flint glass	One centimetre thickness transmits from 50 to 80 per cent. at 350 μμ. Less than 1 per cent. is transmitted at 305 μμ.
Uviol glass	Lower limit at 253 μμ.
Fluorite	One centimetre thickness transmits 83 per cent. at 186, and the transparency is still high at 100 μμ.
Rock salt	Transparency is high at 186 μμ.
Quartz	Transmits 94.2 per cent. at 222 μμ and 67.2 per cent. at 186 μμ; at beyond 186 μμ the transparency falls off rapidly.
Calcite	Less transparent than quartz for short waves.
Mica	Strongly absorbs the short waves.
Water	Transparency is high at 193 μμ. At 186 μμ it is less transparent than is quartz.
Glycerine	Transparency is high at 240 μμ.
Canada balsam	Transparency is high at 330 μμ.
Gelatine	Transparent down to 257 μμ.
Air	Transparency is high at 194 μμ; at 186 μμ the absorption is very high, and no waves shorter than 165 μμ are transmitted.

[2] "Theoretical and Physical Chemistry," p. 100 (1914).
[3] *Metallurgical and Chemical Engineering*, 14, 184 (1916).

In the thesis which follows, the similarity between the effects produced by the different forms of radiant energy, namely, radiant heat, light, and electricity, will be pointed out. As subjects for study the following have been selected: "The Effect of Chemically Acting Rays on Chlorine," "The Effect of Chemically Acting Rays on Nitrogen," "The Effect of Chemically Acting Rays on Nicotine," and "The Effect of Chemically Acting Rays on the Hydrogenation of Oleic Acid."

THE EFFECT OF CHEMICALLY ACTING RAYS ON CHLORINE.

In his dissertation on the conservation of energy, Helmholtz [4] classified the chemical actions of light as those "by which the light only gave the impulse to the activity of the chemical change analogous to substances which act catalytically," the rate of reaction being accelerated or retarded by light; and, second, "those where the chemical change is opposed," the radiant energy being converted into chemical energy. The reactions here are reversible, and it is a well-known fact that the rate of reaction in the formation of certain chlorine compounds is accelerated by the action of light.

As examples of this phenomenon may be cited, *first;* the combination of chlorine and hydrogen. That light was a factor of prime importance in bringing about this reaction was demonstrated according to Burgess and Chapman [5] and Mellor [6] by William Cruickshank in 1801.[7]

The work of Gay Lussac and Thenard,[8] Seebach,[9] and Dalton,[10] who studied particularly the explosive combination of these gases under the influence of light, confirmed the phenomena. The question was next discussed by Draper,[11] whose researches were quantitative. He was able to establish the fact that the so-called

[4] "Ueber die Erhaltung der Kraft," 1847, p. 25 (see Ostwald's Klassiker, No. 1).

[5] *J. Chem. Soc. Trans.*, **89**, 1399–1439 (1906).

[6] *Ibid.*, **79**, 216–238 (1901).

[7] *Nicholson's Journal*, **5** (i), 202 (1801).

[8] *Mem. Phys. Chim. Soc. d'Arcueil*, **2**, 340 (1809); *Gilbert's Ann.*, **35**, 8 (1810).

[9] Seebach, 1910; Goethe, Farbenlehre fr. Weigert (*Samm. Chem. und Chem. Tech. Vortrage*, **17**, 183 (1911).

[10] "A New System of Chemical Philosophy," **2**, 189 (1811).

[11] *Phil. Mag.*, **23**, 401 (1843); **25** (3), 9 (1844); **26** (3), 473 (1845); **27**, 327 (1845); "Draper's Collected Memoirs," 1878.

absorption law,[12] which afterwards bore his name, probably because of his having given it prominence in chemical literature, though previously announced by Grothuss [13] and now modified by Bancroft, applies in this phenomenon. He stated that the property of chlorine to combine with hydrogen after exposure to light was permanent, the rays so absorbed becoming latent and the effect lasting an unknown time.

Bodenstein and Taylor [14] have recently conducted experiments to ascertain how long the activity produced by illuminating chlorine persists, and found that it lost its activity in 1/1600 second.

They are of the opinion that statements in the literature relative to the existence of active chlorine for considerable periods are based on experiments carried out with impure gases, the action observed in these cases being due in reality to some entirely different cause.

Very extensive work on the combination of hydrogen and chlorine in the presence of light was carried on by Bunsen and Roscoe.[15] These investigators studied the application of the optical laws for the chemically acting rays and found that the distance law and the reflection laws and Beer's absorption law [16] were valid for the reaction taking place between chlorine and hydrogen in the presence of light. Webster [17] found that certain of the wide bands in the visible spectrum of chlorine do not obey the Beer's law. It has been pointed out that these results are not in accord with the theory of Helmholtz, which assumes a viscous resistance to the motion of a vibrating electron.

Cruickshank [18] has noticed that the reaction was not immediate. Bunsen and Roscoe showed that its velocity increased with time to a maximum, which then remained constant till the reac-

[12] See Draper, *Phil. Mag.*, 9, 195 (1841).

[13] Ostwald's Klass., No. 152, 101; cf. Slater, *Phil. Mag.*, 5, 678 (1853); Goldberg, *Z. wiss. Phot.*, 4, 99 (1906).

[14] *Z. Elektrochem.*, 22, 202–206 (1916).

[15] *Pogg. Ann.*, 96, 373–394 (1855); 100, 43–88 (1857); 101, 235–263 (1857); 108, 193–273 (1859); Ostwald's Klass., Nos. 34 and 38; *Trans. Royal Soc. Lond.*, 381 (1887); *Phil. Trans.*, 146, 355 (1857); 146, 601 (1857); 148, 879 (1859).

[16] Beer, *Pogg. Ann.*, 86, 76 (1852). See Webster, *Phys. Rev.*, 4, 177 (1914); cf. Stark, *Physik.*, 9, 892 (1908).

[17] *Phys. Rev.*, 4, 177–194 (1914).

[18] *Loc. cit.*

tion was complete. They termed this time of delayed action "the period of induction." This so-called "period of induction" has been the subject of much discussion, though the theory relative to it which is accepted most generally at present is that of Van't Hoff, who considers that the period of induction is not a real and genuine characteristic of a simple chemical change, but that its existence is merely an indication that some necessary precaution has been omitted.[19]

Another phenomenon noticed in connection with the interaction of hydrogen and chlorine in the presence of light is the so-called "Budde effect," [20] which is a quick expansion of chlorine brought about by intensive lighting and thought to be independent of any heating effect, because the interposition of a screen of water between the light and chlorine has no effect on the results. Budde's explanation of the cause of reaction between chlorine and hydrogen in the presence of light is interesting, because it is one of the early suggestions concerning the dissociation of gases. The following is quoted from the work of Budde:[21] "Now it is known that in chlorine through insolation there is induced a higher degree of chemical activity. This fact might be accounted for in two ways: (1) by assuming that light increases the attraction between the atoms Cl of chlorine and X of the respective other body; (2) by assuming that light tends to resolve, or actually does resolve, the chlorine molecule into its atoms. Of these two hypotheses, the former does not appear very probable, the less so as in the action of light on silver chloride, for instance, we observe a direct severing of connection between Ag and Cl, while the latter, *à priori* at least, does not provoke any objections. . . . I assume that light in general diminishes the force uniting Cl with Cl, and that occasionally through the coöperation of light and internal motion (heat) a molecule, Cl_2, is actually split up into its constituents, Cl' and Cl'." Richardson [22] verified the work of Budde and describes the construction of a continuous recording actinometer based on the Budde effect. The apparatus consists of two bulbs, one filled with dry air and the other with chlorine, the bulbs

[19] Burgess and Chapman, *Chem. Soc. Lond. Trans.*, **89**, 1399–1434 (1906); cf. Mellor, "Chemical Statics and Dynamics," London (1909).

[20] Budde, *Phil. Mag.*, **42** (4), 290–294 (1871).

[21] *Loc. cit.*

[22] *Phil. Mag.*, 277–284 (1891).

being connected by a tube containing sulphuric acid. The apparatus is suspended from the beam of a balance, so that the flow of sulphuric acid from one bulb to the other produces a movement of the beam which is communicated by means of a lever to a pen and is recorded on a rotary drum. He eliminates the expansion due to heat by an ingenious arrangement. These observations were confirmed also by Recklinghausen [23] and Mellor,[24] who used moist but not dry chlorine. Others have found, however, that the Budde effect and the Draper effect—a sudden expansion followed by a return to original volume when a strong light "as a spark from a Leyden jar is momentarily flashed upon a mixture of chlorine and hydrogen"—though confirmed by Favre and Silberman, and Amato,[25] were due to impurities in the gas, and the effects were not obtained by Baker [26] when the pure gas was used. Shenstone,[27] like Baker, found no change in volume when light acted on pure dry chlorine. Bevan [28] showed that activity of the form of chlorine reported by Bunsen and Roscoe was attributable to the presence of water. Pringsheim [29] observed that, when heated and dried, gases exploded not so quickly as moist gases, but just as violently. Dixon and Harker as early as 1889 [30] pointed out that the more carefully the mixture of gases was dried the greater was the intensity of light required to cause detonation in hydrogen chlorine mixtures, but that an electric spark always caused an explosion at once, no matter how carefully the gases were dried. These experimenters measured the rate of propagation of the detonation wave and showed it to be greater in dry than in moist gases, from which they conclude that moisture retards rather than accelerates the reaction. This phenomenon is surprising in view of the fact that there are innumerable reactions that apparently will not take place in the absence of moisture. As early as 1802, Mrs. Fulhame [31] called attention to the necessity of moistening gold salts before reducing them with

[23] *Z. phys. Chem.*, 14, 494 (1894).
[24] *J. Chem. Soc.*, 1284 (1902).
[25] Cf. Mellor, *Loc. cit.*
[26] Brit. Assoc. Rept., 493 (1894).
[27] *J. Chem. Soc. Trans.*, 71, 471–488 (1907).
[28] *Proc. Roy. Soc.*, 72, 5 (1903).
[29] *Ann. Phys. Chem.*, 32, 422 (1887).
[30] "Manchester's Memoirs," 3, 118 (1889); 4, 1 (1890).
[31] Cf. Thompson, "A System of Chemistry," 2, 454 (1802).

hydrogen or by "phosphorated ether." A short while later Higgens [32] observed that dry hydrochloric acid did not act on calcium carbonate. According to Bigelow,[33] strictly dry silver chloride is hardly sensitive to light. A brief *résumé* of the early reports on these phenomena is given in the paper of Mellor and Russell,[34] who refer to Baker [35] for a complete list of later works on the phenomena.

Fabre and Silbermann [36] sought to find a heat change in illuminated chlorine absorbed by solution of potassium hydroxide. They reported a noticeable difference between the action of illuminated and unilluminated gas, and a greater amount of potassium chlorate formed by illuminated chlorine. These results were shown, however, to be false by Berthelot [37] and Mellor.[38] Later Mellor [39] showed that the Budde effect was due to the heating action of the absorbed rays. In a series of papers on the "Union of Hydrogen and Chlorine" Mellor [40] gives a review of previous work on many different phases of the subject and reports personal experiments. To follow these interesting researches would carry one too deeply into the subject for the immediate purposes of this paper, so that the following references are added as an aid to those who are particularly interested in this reaction: [41]

[32] "Experiments and Observations on the Atomic Theory," 1814; cf. Mellor and Russell, *Loc. cit.*

[33] *Loc. cit.*, p. 368.

[34] *Loc. cit.*

[35] *Journ. Chem. Soc. Trans.*, 64, 611 (1894).

[36] *Ann. Ch. Ph.*, 37, 497 (1853).

[37] *Ann. Chem. Ph.*, 5, 322 (1876).

[38] *J. Chem. Soc.*, London, 81, 1280 (1902).

[39] *Loc. cit.*

[40] *J. Chem. Soc. Trans.*, 79, 216–238 (1901); 81, 1292–1301 (1902).

[41] Chapman and MacMahon, 'The Interaction of Hydrogen and Chlorine," *J. Chem. Soc.*, 95, 135–138; 959–964; 1717–1720 (1909); 97, 845–851 (1910); Sirk, "Hydrogen and Chlorine in Heating and Under the Influence of Light," *Z. physik. Chem.*, 61, 545 (1908); Bodenstein and Dux, "Photochemical Kinetics of Electrolytic Chlorine-Hydrogen Mixtures," *Z. physik. Chem.*, 85, 297–328 (1913); *Physik. Elektrochem.*, 19, 836–856 (1913); Taylor, "The Interaction of Hydrogen and Chlorine Under the Influence of Alpha Particles," *J. Am. Chem. Soc.*, 37, 24–38 (1915); *Ibid.*, 38, 280–285 (1916). Bodenstein, *Z. angew. Chem.*, 28 (3), 621 (1915).

First, the decomposition of hydrochloric acid.[42]

Second, the oxidation of hydrogen and sulphur dioxide and decomposition of ozone in the presence of chlorine and light.[43]

Third, the action of light on certain chlorine acids.[44]

Fourth, the decomposition of chlorine water.[45]

Fifth, the action of carbon monoxide on chlorine to form phosgene.[46]

Sixth, the substitution of chlorine in organic substances, of which the following are among the noteworthy:

(*a*) In methane.[47]
(*b*) In acetylene.[48]
(*c*) In benzene.[49]
(*d*) In toluene.[50]
(*e*) In xylol.[51]
(*f*) In mesitylene.[52]
(*g*) In acetylbenzol.[53]
(*h*) In chlorbenzol.[54]
(*i*) In tetra-butyl benzene and orth-butyl toluene.[55]
(*j*) In sulphobenzid.[56]
(*k*) In alcohol.[57]
(*l*) In methyl ether.[58]
(*m*) In hydrocarbons of the chain C_nH_{2n} and C_nH_{2n-2}.[59]
(*n*) In acetic acids.[60]
(*o*) In cinnamic acid.[61]
(*p*) In oils, fats, rosins, or paraffin.[62]
(*q*) In compounds contained in natural petroleums.[63]
(*r*) In compounds contained in natural gas.[64]
(*s*) In hydrocarbons.[65]

[42] Coehn and Wassuljewa, *Ber.*, **42**, 3183–3186 (1909); Berthelot and Gaudechon, *Compt. rend.*, **156**, 889–892 (1913); Thiele, *Ber.*, **140**, 4914 (1907).

[43] Weigert, *Ann. Phys.*, **24**, 243–266 (1907).

[44] Pedler, *Proc. Chem. Soc.*, **79**, 65–66 (1890).

[45] Wittwer, *Pogg. Ann.*, **94**, 597 (1853); Bunsen and Roscoe, *Pogg. Ann.*, **96**, 373–374 (1855); Wittwer, *Pogg. Ann.*, **95**, 598 (1885); **86**, 281 (1862); Billitzer, *Jahrb. Phot.*, 82–88 (1907); cf. also Kummell, *Z. Elektrochem.*, **17**, 409–412 (1911); *Proc. Chem. Soc.*, **79**, 65–66 (1890); Benrath and Tuchel, *Z. wiss. Phot.*, **13**, 383–398 (1914); Milauer, *Z. physik. Chem.*, **86**, 564–566 (1914); Dawson, *Z. wiss. Phot.*, **14**, 213–215 (1914); Benrath, *Ibid.*, **14**, 238 (1915); Stobbe, *Z. Ann. Chem.*, **21**, 388 (1908).

[46] Chapman and Gee, *J. Chem. Soc.*, **99**, 1726–1739 (1911); *Proceedings*, **27**, 232–234; Davy, *Phil. Trans.*, **144** (1812); Cordier, *Monatsch.*, **21**, 660 (1900); Dyson and Harden, *J. Chem. Soc. Trans.*, **83**, 291 (1903); Wilderman, *Z. phys. Chem.*, **42**, 257 (1903); Weigert, *Ann. Phys.*, **24**, 55–57 (1907); **24**, 243–266 (1907). Cohen and Becker, *Ber.*, **43**, 130–133 (1910).

[47] Hofmann, *Lieb. Ann.*, **102**; Baskerville, *J. Ind. Eng. Chem.*, **4**, 216 (1912); Baskerville and Riedever, *J. Ind. Eng. Chem.*, **5**, 5–8 (1913); see also *Proc. 8th Inter. Congress Applied Chemistry;* Philips, *Amer. Chem. Jour.*, **16**, 362; Walter, German Patent 222,919, November 5, 1909.

[48] U. S. Patent 908,051, December 29, 1908.

[49] Faraday, *Ann. Chem. Phys.*, **30**, 274; Mitscheruch, *Pogg. Ann. Phys. und Chem.*, **35** (5), 370–374 (1835); Slater, *Z. phys. Chem.*, **45**, 5 (1903); *Ibid.*, **45**, 540 (1903); Bancroft, *J. Phys. Chem.*, **12**, 4 (1908); Luther and Goldberg, *Z. phys. Chem.*, **56**, 43–56 (1906).

It was thought that a study of the formation of certain compounds of chlorine in the presence of artificial light, known to be accelerated by sunlight, would be of value. Chloracetic acid was the first compound selected.

CHLORINATION OF ACETIC ACID.

Chloracetic acid was discovered by Dumas [66] in 1839. After filling flasks with chlorine gas he added not more than nine decigrammes of crystallized acetic acid to each litre of chlorine gas. He stoppered the flasks and placed them so that they were exposed to the direct rays of the sun for a whole day. At the end of this time he found that a substance had been formed which had crystallized from the residue contained in several of the flasks and which by examination he proved to be a true chlorine substitution product of acetic acid.

It has been found that several substances, such as phosphorus and sulphur, greatly accelerate this reaction. A laboratory method for the preparation of chloracetic acid is given in Gatter-

[50] Shramm, *Ber.*, **18**, 606 (1885); Cohen, Dawson and Crosland, *J. Chem. Soc.*, **87**, 1034-1037 (1905); Luther and Goldberg, *Z. phys. Chem.*, **56**, 43-56 (1906); Schluederberg, *J. Phys. Chem.*, **12**, 574-631 (1908); Bancroft, *J. Phys. Chem.*, **12**, 420 (1908); Cohen, Dawson, Blackey and Woodmansey, *J. Chem. Soc.*, **97**, 1623-1636 (1910).

[51] Luther and Goldberg, *Z. phys. Chem.*, **56**, 43-56 (1906).

[52] Zadziewanowski and Schram, *Ber. Krakauer Akad. d. Wiss.*, **61** (1898).

[53] Zadziewanowski and Schram, *Ber. Krakauer Akad. d. Wiss.*, **61** (1898).

[54] Jungfleisch, *Z. Chem.*, **486** (1868).

[55] Salivill, *Bull. intern. acad. sci.*, Cracome A, 606-608 (1910).

[56] Matthews, *J. Chem. Soc.*, **61**, 108.

[57] Schmidt, *J. Pract. Chem.* (2), **19**, 393.

[58] Cahour, *Compt. rend.*, **23**, 1070 (1846).

[59] Romer, *Lieb. Ann.*, **233**, 172.

[60] Dumas, *Lieb. Ann. der Chem.*, **32**, 101 (1839); *J. Pract. Chem.*, **17**, 202; Luther and Goldberg, *loc. cit.*

[61] Nazarov, *J. Russ. Phys. Chem. Soc.*, **47**, 943-955 (1915).

[62] Buchner, U. S. Patent 1,129,165, February 23, 1915.

[63] Tolloczko and Kling, *Abhandl. Krakauer Akad. Wissensch.*, **52**, 295-306; *Ibid.*, 307-316.

[64] Baskerville and Riedever, *Proc. 8th Inter. Cong. Applied Chem.*; see also Baskerville, *J. Ind. Eng. Chem.*, **216** (1912); Phillips, *Ann. Chem. Jour.*, **16**, 362.

[65] DuPont Nemours Powder Co., French Patent 453,406, January 21, 1913; Sparre and Masland, U. S. Patent 1,148,259 (1915).

[66] *Liebig's Ann. der Chemie*, **32**, 101 (1839).

man's "Practical Methods of Organic Chemistry."[67] It has been found by experience that if the experiment there described is carried out with the apparatus placed in the direct rays of the sun for a full summer's day eighty grammes of chloracetic acid is obtained from one hundred grammes of original acetic acid. The yield is dependent upon the amount of sunlight and its intensity.

It is interesting to note, in passing, that Fay[68] found that acetic, propionic, and isobutyric acids were decomposed into hydrocarbons corresponding to the acids and carbon dioxide when acted on by light in the presence of uranium salts.

"In a letter to Goethe in 1811, Seebech intimated that a mixture of hydrogen and chlorine gases contained in a clear glass vessel detonated in the sunshine, whilst under dark-blue glass combination occurred without explosion in one minute, and under a dark-red glass the action took place very slowly or not at all."[69]

Bunsen and Roscoe[70] showed by chlorine-hydrogen mixture that several bands in the spectrum produced maximum effects. They found, further, that the action diminished toward the red end of the spectrum, and regularly decreased in proportion to the distance of the band from the ultraviolet end.

Morren[71] and Gernez[72] showed that in chlorine-filtered light no blue rays are present; and, as only those rays which are absorbed are active, this would indicate that the blue light would be the light which caused the reaction.

Schramm[73] obtained analogous results to those obtained by Bunsen and Roscoe in the action of light on bromine and toluene and ethyl benzol, etc.

Eder,[74] in his summary of observations on the "Chemical Action of the Solar Spectrum," points out that light of every color, from the ultraviolet to the infra-red, can cause chemical action. He calls attention to the fact that each color can have an oxidizing or reducing effect, dependent on the nature of the light-

[67] Page 139 (1909).
[68] *Am. Chem. Jour.*, **18**, 269–289 (1896).
[69] Mellor, *loc. cit.*
[70] *Pogg. Ann.*, **108**, 270 (1859).
[71] *Compt. rend.*, 376 (1869).
[72] *Compt. rend.*, 660 (1872).
[73] *Monatschafte*, 300 (1889).
[74] "Handbuch der Photographie," Ed. 2, 1, 180 (1892).

sensitive substance. He, however, generalizes the oxidation and reduction effects of different wave-lengths by saying that red light usually has a reducing effect. He cites, as an example of reducing action by red light on metallic compounds, the use of sliver salts in the photography of spectra. He also points out that blue and violet lights have the most effect on compounds of the metalloids, giving as an example hydrogen and chlorine mixtures.

In the report of their experiments in connection with work in the substitution products of chlorine and natural gas, Baskerville and Riedever[75] found that blue light from a projection lantern was the most effective light obtainable for the purpose, and, as the laboratory method for preparing chloracetic acid, referred to above, had been successfully carried out in glass apparatus, thus excluding the ultraviolet light, it was thought advisable to attempt to make chloracetic acid, using light from a projection lantern. This will be referred to later.

Since the classical work of Hertz,[76] in conclusion of which he says:

> "We have represented the phenomena investigated by us as rays of electric force. We may, in conclusion, regard them as light rays of very great wave-length. To me at least the experiments described seem eminently fitted to remove all doubt as to the identity of light, radiant heat, and electrodynamic wave-motion. I believe that we shall now with more confidence avail ourselves of the advantages which the assumption of this identity offers, both in the domain of optics and electricity,"

one may accept as a working hypothesis that the forms of radiant energy, radiant heat, light, and electricity, are similar in all essential respects excepting wave-length. Different effects are produced by different wave-lengths. All experimental work tends to prove that radiant energy is due to electrons in motion, and it is important to keep in mind that when radiant energy impinges on an object it may be partly or totally reflected, in

[75] *Loc. cit.*

[76] "On Rays of Electric Force," *Phil. Mag.*, 27, 289–298 (1889) (translated from *Sitzungsb. der Akad. der Wiss. Berlin*, December 13, 1888).

part or totally absorbed, in part or totally converted into other forms of energy, or may partly or entirely pass through unaltered.

That light exerts pressure has been definitely proved.[77] This pressure is an entirely negligible quantity in all our measurements, but on exceedingly small, light objects—for instance, molecules of a highly rarefied gas—it may not be negligible.[78]

Bragg[79] points out that if we reason from the ideas of Planck, Einstein, and others we are led to the thought that light energy is in separate quanta, the shorter the wave-length, the more energy in the quanta. He discusses the question as still open, there being "still something in the corpuscular theory of light,"[80] as light resembles so closely the X-rays, which have much evidence to show them to be due to corpuscles. He points out that Huyghens's other theory was accepted because (1) it was not believed that matter could travel with the velocity of light, but now it has been demonstrated that the alpha particles which are conceded to be material move with about the same velocity, and (2) it was believed that streams of matter could not interpenetrate each other, and now it has been demonstrated that streams can pass each other and that no matter is impenetrable. Huyghens's wave-front, however, still explains reflection and refraction.

Bigelow[81] paraphrases a famous statement of Kekulé as follows:

> "Whether radiant energy be electrons or not, this much is certain, that, granting it to be electrons, it would appear as it now does."

Smiths and Aten[82] made a systematic study of the similarity between the action of light and the silent electric discharge in the formation and decomposition of a number of hydrogen compounds, including hydrochloric acid. When light was employed the gases were led through a thin-walled quartz tube which was

[77] Bigelow, "Theoretical and Physical Chemistry," p. 503 (1914); see also Morris, *Sci. Ass. Sup.*, 76, 18–19 (1913).

[78] *Nature*, 90, 558 (1913).

[79] Cf. Arrhenius, "Das Wenden der Welten."

[80] See also Thompson, *Proc. Camb. Phil. Soc.*, 14, 417, on the "Ionization of Cases by Ultraviolet Light," and on the evidence as to the structure of light afforded by its electrical effects.

[81] "Theoretical and Physical Chemistry," New York, 1914, p. 502.

[82] *Z. Elektrochem.*, 16, 264–267 (1910).

exposed to the rays from a quartz mercury lamp. For study of the effect of a silent electric discharge an ordinary ozonizer was used, the current for which was supplied by an induction coil and condensers capable of giving a one-centimetre spark. They found that when water was present in the gases the silent electric discharge uniformly produced combination or decomposition in all the cases tried; with light the reactions were not so universally proved. When the materials were dry it was found that the reactions were often not obtained on repeated trials, but later very decided reactions were evident.

These results show a similarity in the action of light and silent electric discharge in nearly all the cases tried. These writers point out that a failure by them to decompose the water by the light or electric discharge was not surprising because of the high temperature necessary for the dissociation of water. In this connection it may be mentioned that Thiele [83] has shown that oxygen and hydrogen may be caused to unite by the aid of ultraviolet light.

The discussion of Smiths and Aten as to the conditions under which the reactions take place is very interesting. They state that if light or electric energy is added to a system which is in equilibrium when in the dark or is in thermochemical equilibrium, and the system is sensitive to that form of energy, a new equilibrium is established which differs from the old in that it is thermochemically metastable, since it always agrees with the equilibrium in the dark but not with the electrochemical equilibrium of higher temperatures. They discussed different photo- and electrochemical equilibriums, and the photochemical dissociation equilibrium of hydrogen and chlorine was predicted.

The hypothesis of Smiths and Aten has been confirmed by Coehn,[84] who found that this equilibrium can be demonstrated so conveniently in the reaction between hydrogen and chlorine that the dissociation of hydrochloric acid by light can be demonstrated by a lecture experiment.

Smiths and Aten [85] state that one of them published a series of experiments [86] which proved the above-mentioned law that

[83] *Ber.*, **40**, 4914 (1907).

[84] *Ber.*, **42**, 3183 (1909).

[85] *Z. Elektrochem.*, **16**, 264–267 (1910).

[86] *Koninkl. Akad. von Wetenschappen Amsterdam*, October 30, 1909, p. 386.

photo- and electrochemical equilibriums agree with purely thermochemical equilibrium of higher temperature.[87]

They call attention to the rise in potential between electrodes at the ends of a gas column when the column is acted on by light. This phenomenon occurring at constant temperature would furnish evidence of an increase of the inner energy of the molecule. Both the inner and outer energy of the molecule would increase with the temperature.

Recognizing that the inner energy is the principal factor of a chemical reaction, they base their hypothesis on the fact that the absorption of electrical energy and light energy even at ordinary temperatures brings about equilibriums which are also found by addition of heat energy, although in that case at much higher temperatures.

They point out that this hypothesis leads to an explanation of the enormous velocity of reaction caused by light and electricity because the photo- and electro-equilibrium at the usual temperature agrees with thermic equilibrium of much higher temperature. They also give the conditions under which the law of mass action is applicable to photo- and electrochemical equilibrium. They say that it is applicable when the energy is in such an amount that it has an effect without any apparent diminution of its intensity; *i.e.*, when the system is homogeneous. When, however, it is less intense, then the decrease in energy is plainly apparent; the condition is different from stratum to stratum, and the system is non-homogeneous and the law is not applicable.

Berthelot and Gaudechon[88] performed experiments on the dissociation of gaseous compounds by light; the compounds used including hydrochloric acid, hydrobromic acid, and hydroiodic acid. They showed that in photochemical reactions frequency of vibration plays the same rôle as does temperature in heat reactions, and that for compounds of the same group the stability of hydrogen compounds exposed to light decreased with the increase of molecular weight, paralleling the thermal phenomena. Where only a very elevated temperature caused appreciable dissociation, only the extreme ultraviolet rays caused similar dissociation. This very general statement concerning the similarity in action of temperature and frequency of vibration must, how-

[87] See also Berthelot, *loc. cit.*

[88] *Compt. rend.*, 156, 889–892 (1913).

ever, be considered carefully so that one will not be led into reasoning that light and heat action are identical, which, of course, is not the case.

Goldberg [89] pointed out that the temperature coefficient of reaction velocities of all light-sensitive reactions which had been observed was very small.

Nazarov [90] showed by experiment, in which he made observation on the effect of the addition of chlorine to cinomonic acid in the dark and in the light, that the temperature coefficient of photochemical reactions is approximately such as was to be expected, since photochemical reactions in their initial stages are supposed to be independent of the temperature. This is indeed a most interesting observation, because the chemist is accustomed to consider that no chemical change proceeds at a definite rate, regardless of temperature, with the exception, perhaps, of those taking place in the radio-active elements. Keeping always in mind the fact that a chemical reaction can take place only when the equilibrium between energy of different degrees of intensity becomes unstable, and that this is usually brought about by some apparently external cause, the above considerations impress one with the idea that the action of light in producing the equilibrium of energy which is indicated by the great law " that the energy of the universe tends toward a constant " is a greater factor than has usually been recognized.

Burgess and Chapman [91] have demonstrated by experiments on hydrogen-chlorine mixtures that chlorine can be made active by heat as well as by light. They note the curious fact that the behavior of dilute solutions of chlorine differs from that of more concentrated solutions in that the weak solutions gain considerably in acivity on simply being kept in the dark at ordinary temperatures. In the conclusion of their paper on the " Interaction of Chlorine and Hydrogen " they offer the following suggestion to explain the action of light on the hydrogen-chlorine mixture:

" The light which falls on the moist mixture of chlorine and hydrogen is absorbed, in the first instance, by the colored component (namely, the chlorine), and after it is absorbed it is de-

[89] *Z. phys. Chem.*, 41, 1.
[90] *J. Russ. Phys. Chem. Soc.*, 47, 943–955 (1915).
[91] *Loc. cit.*

graded into heat. During the process of degradation the energy passes through various forms. Now it is conceivable that the distribution of the various kinds of vibration of which the degrading energy is composed will, in certain cases, depend largely on the presence in the system of even small quantities of foreign bodies. A difference in the rate of chemical change might clearly be expected as a result of a marked difference in the character of the energy through which the light passes as it is transformed into heat. Whether the quality of the energy can vary to the degree required by this hypothesis, according as certain impurities are present or not, and whether this variation can be regarded as the chief determining character of the change, is at present purely a matter of conjecture, and awaits experimental confirmation."

According to Lenard,[92] there are three kinds of effects produced when ultraviolet light acts on a gas:

1. "The gas may conduct electricity, owing to the formation of positive and negative ions.[93]

2. "Condensation nuclei may be formed devoid of electric charge.[94]

3. "Chemical molecular change may take place; as, for example, the action of ultraviolet rays on oxygen with the formation of ozone."

All of these reactions are due to the action of the periodic electric forces on the molecules of the gas. Therefore this classification of the kinds of effect produced by ultraviolet light may also apply to effects produced by radiant heat, light, or electricity.

Thomson[95] has shown that when an electric current passes through chlorine, chlorine occurs as Cl, Cl_2, Cl++, Cl+, Cl−; that is, neutral atomic chlorine, neutral molecular chlorine, atomic

[92] Lenard and Wolf, *Ann. Phys. Chem.*, 3 (1899); *Ann. Phys.*, 1 and 3 (1900); see also Lenard and Ramsauer, *Trans. Heidelberg Acad.*, August 2, 1910; August 4, 1911, five parts.

[93] Thompson, "On the Ionization of Gases by Ultraviolet Light, etc.," *Proc. Camb. Phil. Soc.*, 14, 417; Steubing, "Ionization of Gases by Means of Light" (gives summary and bibliography), *Jahrb. Radioakt. Elektron*, 9, 111–137.

[94] Cf. Wilson, *Phil. Trans.*, 192 (1898); 198, 276 (1897); Bevan, *Proc. Roy. Soc.*, 72, 5 (1903); Burgess and Chapman, *loc. cit.*; Wigert, *Ann. Physik.*, 24, 243–266 (1907); Saltmarsh, *Proc. Phil. Soc. London*, 27, 357–369 (1915).

[95] Thomson, *Chem. News*, 103, 265–265 (1911).

chlorine carrying two positive charges, atomic chlorine carrying one positive charge, and atomic chlorine carrying one negative charge.

Townsend,[96] in his paper on "The Electrical Properties of Freshly Manufactured Gases," says that chlorine prepared by electrolysis had a small negative charge, and that the charge on hydrogen varied from positive at first, when a new electrode was used, to a minus charge of definite value after use. An old electrode was found to give negatively charged hydrogen.

Shenstone,[97] after an experiment in which he attempted to form a compound similar to ozone, concludes that highly purified chlorine remains almost unaffected by the "ionization discharge."

Ludlam[98] conducted a series of experiments to show the nature of the action of ultraviolet light on chlorine. He states in his conclusion that pure chlorine is not ionized and that it does not form condensation nuclei, and, further, that chlorine in considerable quantities destroys the ions and nuclei otherwise found in the air.

Thompson[99] found no free-charged ions to be present during the combination of hydrogen and chlorine under the influence of light, and, further, that artificial production of free ions (*i.e.*, by Röntgen rays and radiation from thorium in the mixed gases) did not affect the rate of their combination. It may be mentioned, in passing, that probably the credit of being the first to find quantitative evidence to support the idea that a close relationship exists between ionization of a gas and chemical reactions induced in it by radio-active influence should be given to Lind.[100]

An interesting theory of photochemical reaction velocities has been advanced by Bodenstein.[101] He regards the initial absorption process in any photochemical change as a photo-electric effect. The molecule is ruptured at the expense of the absorbed light energy into a positive radical—an atom, or, with more complex substances, a molecule, with a free valence and a free elec-

[96] *Pro. Cambr. Phil. Soc.*, 9, 345–371 (1897), and *Phil. Mag.*, 45, 125 (1898).

[97] *J. Chem. Soc. Tran., London*, 71, 486 (1897).

[98] *Phil. Mag.*, 23, 757–772 (1912).

[99] Thompson, *Proc. Camb. Phil. Soc.*, 11, 90–91 (1901).

[100] Lind, *J. Phys. Chem.*, 16, 564 (1912).

[101] Bodenstein, *Z. physik. Chem.*, 85, 330 (1913).

tron. He believes that both portions may lead to chemical reaction, the positive radicals because they are chemically exceedingly active, and the electrons because they may attach themselves to molecules and so activate them that they take part in the chemical change. Bodenstein classifies light reactions into primary light reactions, in which the positive radicals enter into the combination, and secondary light reactions in which the molecules activated by the electrons take part in the reaction; the electrons, after the reaction has occurred, being again free to attach themselves to and activate other molecules.

Commenting on this theory of Bodenstein's, Taylor[102] points out its application to all such chemical reactions that are effected under the influence of other forms of energy, provided that under such influence the rupture of the molecule with the formation of free electrons may be postulated. He later states that "the hypothesis originally put forward by Bodenstein to account for the kinetics of the photochemical reaction covers equally well the facts obtained from this radio-active study."

Taylor, following closely the ideas of Bodenstein, outlines the processes which are supposed to take place when an alpha particle passes through a mixture of hydrogen and chlorine. In this outline he assumes ionization and decomposition of the chlorine molecule into positively charged radicals and electrons.

Ludlam [103] shows that chlorine does not easily lose electrons, and says that this is what might be expected because of its electronegative character; affinity for negative electricity being a characteristic of electronegative elements. He considers hydrogen as being on the borderland, taking its position among the noble metals, by nature of its electrochemical properties. It is, however, more distinctly positive than copper, even at atmospheric pressure. Ludlam offers as an explanation of the action between hydrogen and chlorine the possibility that an atom of hydrogen under the influence of light emits an electron, which immediately attaches itself to an atom of chlorine, chemical combination taking place. In considering this theory it must be kept in mind that there is much evidence to show that a reaction takes place when the chlorine alone is acted on by light and subsequently led into the presence of hydrogen. Lenard and Ramsauer [104] sug-

[102] *Loc. cit.*
[103] *Loc. cit.*
[104] *Loc. cit.*

gest that the light splits up the chlorine molecules into two neutral atoms. It was pointed out that traces of foreign matter appear necessary for the ionization of gases and for their chemical combination, and yet actual liberation of electrons for a measurable period of time does not appear to be a precursor of gaseous combination.

Vernon [105] found that the silent electric discharge brought about a slight increase in volume in chlorine or a mixture of chlorine and bromine, which was accounted for by the heat effect on the gas.

Kellner, in the same year (1891), took out a patent,[106] in which he claimed to increase the bleaching power of chlorine by means of an electric discharge. For this purpose Barmemores has taken out a patent [107] in which he describes an apparatus for applying the principle of increasing the bleaching action of chlorine by the same means.

Kellner,[108] in a paper, "On the Conduct of Bromine Under the Influence of a High-frequency Discharge," reports finding a decided change in bromine, and states without elaboration that chlorine under the action of an electric discharge showed properties different from the ordinary chlorine, and that it combined in the dark with acetic acid.

According to Mellor,[109] chlorine acted on by light first and then passed into hydrogen does not form hydrochloric acid. Mellor and Russell [110] carefully prepared pure dry chlorine and reported experiments on its action on hydrogen in the presence of an electric spark, heat, and sunlight. They conclude, from their results, that the electric spark causes explosion in either moist or dry chlorine-hydrogen mixture, and because the combination was found to be complete they conclude that the action was propagated through the whole mass. Neither heat nor sunlight caused explosion in the dried gas combination; when combustion occurred at all it occurred slowly and incompletely, and was not transmitted through the whole of the gas, as in the case where the electric discharge was used.

[105] *Chem. News*, 63, 67 (1891).
[106] E. P. 22,438, December 23, 1891; D. F. R. 67,980, February 5, 1892.
[107] Ost. P. 11,180, October 15, 1902.
[108] *Z. Elektrochem.*, 8, 500–504 (1902).
[109] *Loc. cit.*
[110] *J. Chem. Soc. Tran.*, 81, 1272–1280 (1902).

Briner and Durand[111] found that there was no polymeric variety of chlorine formed when chlorine was acted on by the electric discharges. They express the opinion that the observations of Kellner, who reported an active form of chlorine, were probably erroneous; the active form "being in reality attributable to the formation of ozone or oxides of chlorine in the impure chlorine used by Kellner."

Kummell[112] states that there is no molecular change when chlorine is acted on by light, and, after referring to previous work on the subject,[113] proceeds with experiments showing that dry chlorine acted as did nitrogen, hydrogen, carbon monoxide, and oxygen, though moist chlorine showed an apparent ionization in the dark, which was greatly accelerated by light. Kummell showed that this was due to the formation of hydrochloric acid from water and chlorine. A rapid discharge of the electroscope used to measure the charge was obtained when the hydrochloric acid content was increased, but no discharge resulted when 20 to 40 per cent. of oxygen was mixed with moist chlorine, in order if possible to bring about a reversal of the reaction.

Le Blanc and Valmer,[114] in answer to the question, "Does ionization of chlorine 'knall gas' commence on exposure to light?" found no such ionization, and they suggest that the values found by Kummell were the result of defective insulation. They found, however, that Röntgen rays caused a chemical reaction to take place.

It may also be noted that Melander,[115] in reporting their researches on the rate of reaction between chlorine and hydrogen when heated, stated that chlorine heated previous to the reaction with hydrogen gave no evidence of increased activity. They noted that the reaction was bimolecular and increased by addition of sulphur dioxide or sulphuric acid.

(To be continued.)

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[111] *Z. Elektrochem.*, **14**, 706–707 (1908).

[112] *Z. Elektrochem.*, **17**, 409–412 (1911).

[113] Wobig and Kummell, *Z. Elektrochem.*, **15**, 252–254 (1909); Budde, *Ber.*, **459** (1871); Melloni, *Jahresber. d. Chem.*, **180** (1871), and Pringsheim, *Ann. d. Physik. und Chem.*, N. F. **32**, 384 (1887).

[114] *Z. Elektrochem.*, **20**, 494, 497 (1914).

[115] *Archiv. Kemi. Min. Geol.*, **5**, 22 (1914).

THE METALLURGY OF TITANIUM.*

BY

ROBERT J. ANDERSON, B.S., Met.E.,

Cleveland, Ohio.
Metallurgist, The Cleveland Metal Products Company.
Member of the Institute.

In Open-hearth Practice.—In acid open-hearth work the same general procedure is followed, except that the ladle should be held longer, usually about five to ten minutes, in order that the impurities scavenged out by the titanium may have time to pass out into the slag. There appears to be no reason for this other than the experience of practical operators. In case the titanium alloy is added in the furnace, great care must be observed to prevent its contact with the slag, and it should be as quickly and as thoroughly rabbled into the bath as possible. The steel should be tapped at once, as delay will but undo the work already performed by the alloy. In basic open-hearth practice, usually it appears expedient to add about 75 per cent. of the ferro-manganese in the furnace and the rest in the ladle with the ferro-silicon. The addition of these ferro-alloys to the ladle should be rapidly followed with the titanium alloy addition, observing the precautions already stated for keeping it from contact with the slag. Charles V. Slocum urges that the titanium alloy should not be pre-heated before adding to a bath of steel or iron. Doctor Moldenke, on the other hand, speaks of the "necessity" of heating the alloy red hot before using it. Practical experience shows that it does the work cold as well as hot, and the general tendency is to use it cold. However that may be, it would appear that heating the alloy, or using it liquid, as is the coming European practice with ferro-manganese, would facilitate its readier incorporation into the metal. As to whether it should be used in conjunction with aluminum there is no agreement among metallurgists. The evidence seems to favor those who claim that titanium should never be used in conjunction with aluminum. The size of pieces of alloy to be added in open-hearth heats

* Continued from page 508, vol 184, October issue.

depends on the size of the heats; in general, the larger the heat tonnage, the larger the pieces of alloy may be. Thus for heats over 25 tons pieces screened through a 0.75-inch screen are recommended.

In Electric Furnace Practice.—Of all the appliances used for the production of liquid steel, the electric furnace admittedly does give a thoroughly deoxidized metal. At any rate, whether the steel has been thoroughly deoxidized in the furnace or not, it will be somewhat reoxidized during tapping into the ladle, and slag will become entangled with the metal during this period. In case the electric furnace is acid-lined instead of basic, the operation is simply one of melting, and deoxidation must be secured. For electric-furnace practice, whether acid or basic, it may be well to add titanium alloy during the tapping of the steel into the ladle in the same way as in Bessemer and open-hearth work; and, as usual, the steel should be held for about five or more minutes to allow the reaction to take place and to permit the entrained slags and oxides to rise to the surface. The modern metallographic microscope has shown that titanium-treated steels contain included particles of a pinkish substance, now identified as titanium nitride crystals, so that it is extremely doubtful whether, under the conditions of the present fast practice, this compound finds its way into the slag at all. Regardless of that, its presence appears to do the steel no particular harm.

In Crucible Practice.—In the crucible process the best results have been secured by adding the titanium alloy to the pots before they are removed from the furnace and allowing time for the chemical reactions to take place before teeming.

Effect of Titanium on Cementation.—The work of Leon Guillet[71] indicates that it is proved that the substances which retard cementation are those which are found in solution in the iron, as Ni, Ti, Si, and Al, and that the substances which accelerate cementation are those which seem to exist in the state of double carbides, substituting a part of the iron of the cementite, as Mn, Cr, W, and Mo. He has constructed Table IV from data secured from experiment.

[71] Guillet, Leon, "La cementation des aciers au carbone et des aciers speciaux," *Memoires et compte rendu des travaux de la Société des Ingénieurs Civils de France*, series vi, No. 2, February, 1904.

TABLE IV.

Proportion of foreign metal	Velocity of penetration in tenths of a millimetre	Proportion of foreign metal	Velocity of penetration in tenths of a millimetre
2% Ni	7	2% Mo	11
5% Ni	5	1% Ti	8
0.5% Mn	11	2% Ti	7
1.0% Mn.	12	0.5% Si	6
1.0% Cr.	10	1.0% Si	5
2.0% Cr.	11	2.0% Si	4
0.5% W.	9	5.0% Si	0*
1.0% W	9	1.0% Al	4
2.0% W	12	3.0% Al	2
1.0% Mo	9		

*No cementation

NOTE.—Under the same conditions a carbon steel showed a penetration of 0.90 mm.

Titanium in Rail Steel.—The question of the manufacture of sound homogeneous steel for rail production is one that has had a great deal of attention by metallurgists, maintenance engineers, and others interested in the subject. A great deal of data has been secured relative to rail wear, and many lengthy reports have been formulated on the subject. Among others prominently connected with the rail question have been Hunt, Dudley, Wickhorst, and Waterhouse, who have contributed to the advancing technique of rail manufacture in no small measure. In this country practically all rails of heavier section for main-line track are now produced from ingots cast from basic open-hearth steel. Acid-Bessemer rails fell into disrepute some time ago. On curves manganese-steel rails have found some favor, as their wearing qualities will stand the higher cost; for straight-away track manganese steel is prohibitively costly. It has just been said that most rails are now made from basic open-hearth steel, and it may be more completely stated that the open-hearth is used in connection with duplexing practice; *i.e.*, a combination of the Bessemer and open-hearth furnaces, where the steel is desiliconized and partly decarburized in the acid-Bessemer converter, and then finished in a basic open-hearth furnace. Roughly, open-hearth steel-rail specifications call for rails within this chemical composition: carbon, 0.55 to 0.85 per cent.; manganese, 0.60 to 0.90; silicon, less than 0.25; and phosphorus, less than 0.04 to 0.06 per cent. More elaborate specifications have been drawn up by the rail committees of the American Society for Testing Materials and of the American Railway Engineering Association, but these need not be further mentioned in this place.

Segregation in Rail Steel.—Segregation is one of the most important questions before the rail-steel maker. According to the now well-known selective freezing of certain molten alloys, and in this case steel, the upper-central part of a steel ingot usually shows the segregation of carbon, phosphorus, and sulphur. In all commercial practice the bulk of the ingot must be used, and it appears to be a hide-bound attitude that calls for a definite percentage of discard as crop from the top of the rolled ingot. Gathman tops and other appliances for keeping the tops hot or for raising the pipe up into the head presuppose that the steel is bad to start with. The production of sound homogeneous steel at the outset, before pouring, appears to be a *desideratum,* as recognized of late by W. C. Cushing.[72] The usual discard of 9 to 10 per cent. or more may not entirely eliminate the segregated portion, although it may crop off the pipe if there is one. George B. Waterhouse[73] shows the results of a number of experiments conducted on segregation in acid Bessemer-rail steel. A comparison was made of ordinary carbon steel ingots and steel ingots treated with 0.25 per cent. by weight of titanium in the form of a ferro-alloy. Very briefly, his results point out that there is much less sulphur segregation in titanium-treated steel than in ordinary steel, and the same thing applies to the segregation of phosphorus and carbon. The use of the alloy brought about a greater uniformity in the steel and, on the whole, lessened the segregation. The photographs in Figs. 9 and 10 are of an ordinary and a titanium-treated ingot. The most marked feature is the increased soundness of the titanium-treated metal because of the concentration of the blowholes into the pipe cavity. The use of aluminum is condemned by some railroad engineers because of the fact that the product of the reaction, viz., alumina, is highly infusible and remains in occluded form in the metal.

As previously pointed out, a great deal of data has been gathered relative to the rail question, and in view of this it appears to be somewhat of an idle ceremony to attempt to recast the writings in this short work. As Professor Richards aptly remarks:[74] "A. J. Rossi and The Titanium Alloys Manufacturing

[72] Engineer Maintenance of Way, Pennsylvania Lines.

[73] Waterhouse, George B., "The Influence of Titanium on Segregation in Bessemer-rail Steel," A. S. T. M. meeting, Atlantic City, June–July, 1910.

[74] Richards, Joseph W., "The Metallurgy of the Rarer Metals," *Met. and Chem. Eng.*, July 1, 1916, vol. xv, No. 1, p. 26.

Company are the alpha and omega of the titanium industry. . . . A finely written booklet of over 100 pages . . . tells the whole story, so why rehearse it here?" The series of booklets entitled "Rail Reports," issued by the same company, gives quite complete account of the function of titanium in the metallurgy of rail steel. It will suffice, therefore, to point out very briefly the marked improvement in rail steel effected by the use of titanium. Microscopic examination of steel treated with ferro-carbon titanium and rolled into rails and corresponding steel not so treated gave the results illustrated in the photomicro-

FIG. 9.

Ordinary steel ingot. (After Waterhouse.)

FIG. 10.

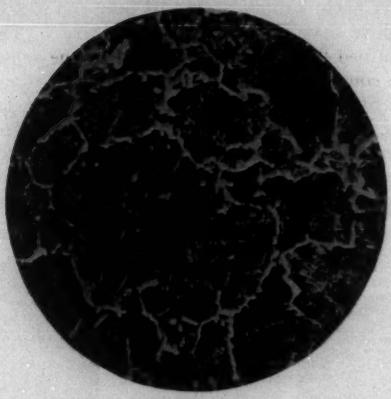
Titanium steel ingot. (After Waterhouse.)

graphs[75] in Figs. 11 to 16. The untreated steel shows an extremely coarse grain, indicating that the metal had been rolled very hot; it shows also a thick ferrite network and much decarburization in the flange of the rail. The treated rail contains only traces of ferrite, except at the surface, and is unsegregated.

Titanium was first used in this country in November, 1907, in a heat of Bessemer steel, under the direction of S. S. Martin, at the works of the Maryland Steel Company. At the first trial

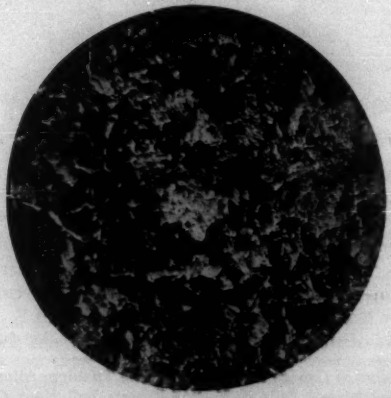
[75] Permission of George M. Comstock, The Titanium Alloys Manufacturing Company, Niagara Falls, N. Y., Rail Reports, Bull. No. 7, *Open Hearth*, 1914, p. 29.

FIG. 11.



Section of untreated steel rail from top of head; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 12.



Section of treated steel rail from top of head; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

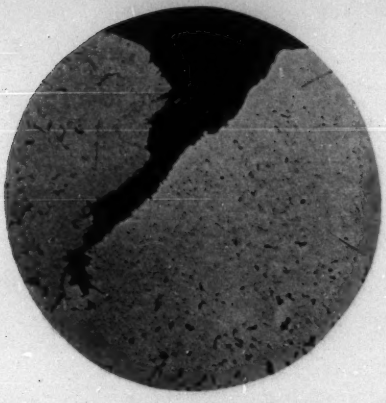
FIG. 13.

Section of untreated steel rail from web; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 14.

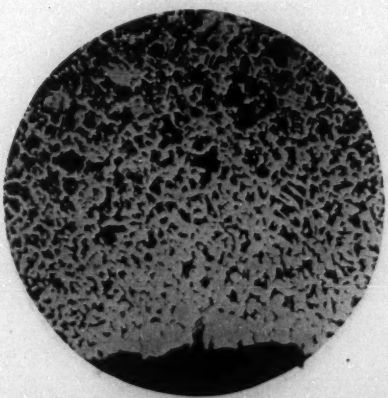
Section of treated steel rail from web; etched to darken pearlite, leaving ferrite white. × 100 diameters. After Comstock.)

FIG. 15.



Section of untreated steel rail from flange; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 16.



Section of treated steel rail from flange; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

the steel showed such improvement that succeeding trials were made shortly after, which developed the remarkable features now so well known. Very exhaustive tests were made at the Lackawanna Steel Company's works in 1908, under the direction of a railroad engineer. The results of these tests and the experience of succeeding years endorse the merits of the titanium alloys for rail-steel manufacture. In short, the beneficial effects of the titanium treatment from the standpoint of the rail user are: (1) Increased rail life of from 200 to 400 per cent.; (2) tougher rails under the drop test; (3) strong steel; and (4) less flaking off of the metal in the head.

Titanium in Pipe Steel.—As in the metallurgy of liquid steel for the manufacture of other semi-finished products, titanium finds employment in steel to be used for pipe or tube production. What has been said elsewhere concerning the desirability of producing sound, homogeneous ingots for rolling into shapes applies here. Both pipe and tube (the two terms are used somewhat interchangeably, although the technical distinction between pipe and tube is that tubes are rated according to the outside diameter, and pipes according to the inside diameter) are made from wrought iron and steel by either lap welding or butt welding. Lap-welded pipe is made from scarfed skelp usually, and butt-welded pipe from grooved skelp, so that there will be avoided the excess of metal at the seam when otherwise no provision is made for that purpose. At times the presence of oxides and slag will make the welding of pipe or tube difficult, and such a product may be rejected as defective.

Titanium in Steel Castings.—The manufacture of steel castings, whether by the acid or basic open-hearth, the Bessemer or Tropenas converter, or in electric furnaces or crucible pots, presents certain inherent difficulties not found in the production of ingots for rolling. The reason for this lies mainly in the fact that the castings represent finished products as such, excepting, of course, the usual annealing, sand blasting, and other cleaning which they receive. Design of castings and expert pattern shop practice play an intimate part in good casting procedure, so that the problem is not a metallurgical one alone. Cracks and blowholes are common annoyances. The reason for the occurrences of cracks in steel castings is a question relative to which there has been much debate and little satisfactory information. Sulphur

is commonly blamed for the presence of cracks, as well as red shortness. Blowholes are usually attributed to the escape of dissolved gases during solidification, which are pent up in the metal at freezing. Irrespective of the causes of unsoundness of steel castings, the production of a uniform product free from defects is a *desideratum*. Since the use of titanium thoroughly deoxidizes molten metal, its employment in steel casting practice would appear to aid in the production of good steel or even make good steel better.[76] W. A. Janssen carried on some experiments with the object in view of conserving his manganese supply by substituting a titanium alloy in part for ferro-manganese in making steel castings. This probably is the first well-defined attempt in that direction other than the use of spiegeleisen by some makers in the past year for the same purpose.[77] In any event, the use of a titanium alloy in steel casting manufacture is no longer a new procedure, but rather must be regarded as a necessity to overcome the vagaries of modern practice. The photomicrographs in Figs. 17 and 18 indicate the scavenging action of titanium on steel, the slag particles being noticeably smaller in the titanium-treated metal than in the plain untreated steel. The photograph illustrated in Fig. 19 shows a type of steel casting treated with carbon-free ferro-titanium.

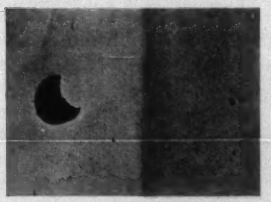
Titanium in Forging Steels.—Forging steels (*i.e.*, steel produced in the semi-finished forms of blooms, billets, or other shapes for treatment under the hammer) are made in a wide range of analyses, but usually within the limits of from 0.10 to 1.25 per cent. C. In spite of the fact that sound, homogeneous steel may be made, it so happens that ill-advised hammer operation will give rise to a poor product. The subject of finishing temperatures for hammer forgings seems to have been given but little attention, and the practice in some shops which the writer has observed has been, if anything, malpractice. As in

[76] Janssen, W. A., "The Use of Titanium in the Manufacture of Steel Castings," paper read at American Foundrymen's Association meeting, Cleveland, 1916.

[77] Spiegeleisen, of course, could not be employed satisfactorily, as it will add too much carbon to the steel. The question of manganese conservation has been dealt with by the author in another place; see "The Metallurgy of Ferro-manganese," *Iron Trade Review*, March 29, 1917, pp. 723–726; and "Ferromanganese in the Iron and Steel Industry," this JOURNAL, May, 1917, p. 579 *et seq.*

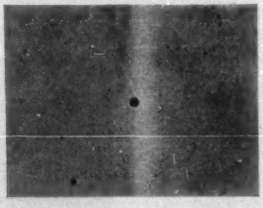
the case of steel-castings manufacture, the production of forgings is not alone dependent upon the nature of the steel. The question of correct finishing temperatures is quite without the scope

FIG. 17.



Typical silicate or slag inclusion in plain steel. × 200 diameters. (After Janssen.)

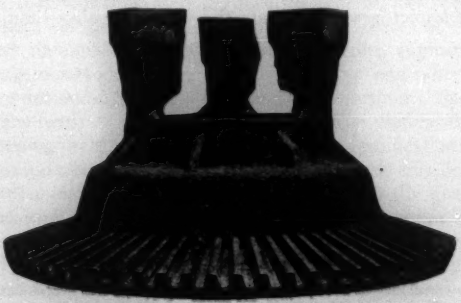
FIG. 18.



Typical small silicate or slag inclusions in titanium-treated steel. × 200 diameters. (After Janssen.)

of this writing, but its importance is recognized. From the standpoint of steel metallurgy, the most common defects in forgings which can be traced to bad steel are segregation and seams. When ingots containing blowholes and occluded oxides and slag

FIG. 19.

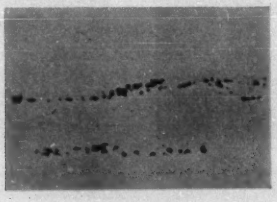


Steel crusher gear weighing 5500 pounds, treated with carbon-free ferro-titanium. (After Goldschmidt Thermit Company.)

are cogged down in a universal mill, and then rolled into billets or not, the occluded substances are elongated in the direction of rolling. Blowholes do not close and weld during either rolling or forging, because the surfaces are oxidized and not clean.

Forging aggravates these annoyances, as deep-seated ingot occlusions may become surface defects through shaping of the section. Hence it is apparent that the only remedy is the production of a cleaner steel. The employment of the chipping hammer for the removal of seams and cracks in forging billets is a makeshift at

FIG. 20.

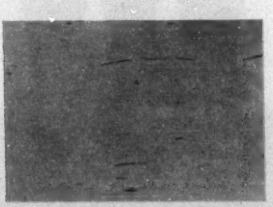


Streaks of alumina in a billet of forging steel deoxidised with aluminum. Section cut parallel to direction of rolling, not etched. × 200 diameters and reduced one-half. (After Comstock.)

best, but where steel makers cannot see the light it is virtually their only salvation. Practical experience shows that the chipping hammer will remove surface defects, but its employment is extremely costly.

Photomicrographs indicate the value of using titanium for

FIG. 21.



Typical small sulphide and silicate fibres in a billet of forging steel treated with titanium. Section cut parallel to direction of rolling, not etched. × 200 diameters and reduced one-half. (After Comstock.)

the elimination of occluded oxides and slag from liquid metal before pouring. Figs. 20 and 21 show the comparative values of aluminum and titanium as deoxidizers.

Titanium in Sheet and Plate Steel.—It is rather doubtful if defects are so noticeable in any other kind of finished steel prod-

ucts, with the possible exception of wire, as in sheets and plates. Sheets for fine automobile-body and fender work, in particular, must be free from surface flaws and defects, and, as elsewhere, the accomplishment of this *desideratum* leads us back to a consideration of the liquid steel. Any ingot defects will certainly be brought to the surface of sheets or plates by the repeated rollings. Steel for plate and sheet-rolling work is made in the usual manner, with the exception of the procedure of adding ferro-phosphorus in the ladle if thin sheets are to be rolled. Other than to the quality of the steel, the causes of defective sheets and plates may be traced to improper rolling and annealing, or to ill-advised pickling practice. These matters are, needless to remark, without the scope of this writing, and no further reference can be made to them here. The question, so far as we are concerned, then lies in the production of good liquid steel, and what has been already said in regard to the use of titanium applies to the production of steel for this purpose.

Titanium in Structural Steels.—Structural shapes, such as channels, angles, tees, I-beams, etc., are rolled in structural-shaping mills, the cast ingots being first cogged down into blooms and then rolled into the various shapes. Most metallurgists have believed that structural steel is rolled, in general, too heavy for the purpose for which it is destined, and differences of opinion have been no uncommon matter between designing engineers and steel makers. Modern office buildings, bridges, and other structures are demanding heavier and still heavier sections. Specifications vary with cities, and there is but little standardization. Disregarding the questions of both design and specifications, there is no question but that segregation is the most serious defect in structural metal. Lives are often dependent on the quality of the steel, and, with this consideration at hand, it seems to be a rather singular thing that the subject has not received more attention. However all that may be, anything which will produce better metal is greatly to be commended, and the results of experimental tests and the usage of practice recommended the titanium alloys for treating the liquid metal before teeming into ingots.

Titanium in Wire Steel.—Steel for wire manufacture is produced in the usual way, ingots being cast in moulds from liquid steel, and the ingots then rolled into billets of small cross-section for drawing. Wire drawing is accomplished by pulling the wire

through succeeding smaller dies, the metal being heated so as to be plastic. The small diameter to which the wire is reduced in comparison to the cross-section of the original ingot clearly indicates how internal defects will be brought to the surface. Certain defects of wire, such as a scaly surface due to spongy metal, hard spots due to segregation, and others, are directly traceable to the liquid steel. Other numerous defects are due to wire-drawing practice. Where the steel can be made sound, that should be done. The use of proper deoxidizers, aided by titanium alloys, will eliminate the defects due to the steel to a large extent.

Titanium is an Alloying Element.—Titanium can be obtained in cast iron produced by smelting titanic iron ores, but it is extremely difficult to introduce the element into steel as an alloying constituent.[78] The experiments of W. H. S. Shakell may be instanced to demonstrate the statement just made; a titaniferous sand from New Zealand containing 97.21 per cent. $FeO + Fe_2O_3$, 0.22 MnO, 0.16 Al_2O_3, 0.50 Si, 1.60 per cent. Ti, and CaO, MgO, and alkalies in insignificant amount, was mixed with suitable fluxes and reduced by coke in crucibles. A white pig iron containing 2 to 3 per cent. Ti was secured. The pig iron was reduced with ferro-manganese and a small amount of oxidized metal, giving a steel containing 0.70 per cent. combined carbon, 0.112 Si, 0.623 Mn, 0.098 S, 0.030 per cent. P, and Ti *nil*. This indicates that titanium is much more easily oxidized than silicon.

(*To be continued.*)

[78] Harbord and Hall, "The Metallurgy of Steel," London, 1911, pp. 402–403.

PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS,

Professor of Meteorological Physics, United States Weather Bureau.

WINDS DUE TO SIMULTANEOUS ADJACENT LOCAL HEATING AND LOCAL COOLING.

Thunderstorm Winds.

Shortly, say twenty minutes or so, before the rain of a thunderstorm reaches a given locality the wind at that place, generally light, begins to die down to an approximate calm and to change its direction. At first it usually is from the south or southwest in the extra-tropical portion of the northern hemisphere; from the north or northwest in the corresponding portion of the southern, and in both more or less directly across the path of the storm itself. After the change, it blows for a few minutes rather gently, directly toward the nearest portion of the storm front, and finally, as the rain is almost at hand, abruptly and in rather violent gusts away from the storm and in the same direction that it is travelling, a direction that usually differs appreciably from that of the original surface wind. Generally this violent gusty wind lasts through only the earlier portion of the disturbance, and then is gradually but rather quickly succeeded by a comparatively gentle wind, which, though following the storm at first, frequently, after an hour or so, blows in the same general direction as the original surface wind.

The chief cause of these and all other winds peculiar to the thunderstorm, except those within the cumulus cloud itself, is the juxtaposition of warm air immediately in front of the rain and a column or sheet of cold air through which the rain is falling. How this temperature distribution is established and what the results are will be explained later in the chapter on the thunderstorm.

* Continued from page 551, vol. 184, October, 1917.

CHAPTER VIII.

ATMOSPHERIC CIRCULATION (*continued*).

Winds Due to Widespread Heating and Cooling.

GENERAL REMARKS.

SINCE the atmosphere is a fluid whose viscosity is not only small but also well known, one might suppose, with respect to any given portion, that it would be quite as easy, through the equations of thermodynamics and hydrodynamics, to foretell its every movement and future position as by the equations of celestial mechanics to predict an eclipse or an occultation. But this is far from being the case, and for many reasons. Thus the irregularities of surface heating and surface friction, and the action of mountains, themselves irregular and broken, in deflecting winds, both horizontally and vertically, complicate the problem beyond exact solution. Besides, there are even discontinuities in the amount of atmosphere involved. Water vapor is added in large amounts by evaporation to the volume of circulating gases, mainly in the regions of "highs," while equal average quantities are withdrawn (not simultaneously) by precipitation, chiefly in the regions of "lows." Hence an exact mathematical solution of the problem of world-wide circulation does not seem possible. Nevertheless, many details of this circulation are clearly understood from physical considerations and admit of at least approximate analyses. Some of these details pertain equally to all the more general winds, and therefore a discussion of them will be given independently as a common introduction to the more extended accounts of certain types of atmospheric circulation that follow under the captions monsoons, hurricanes, trade winds, cyclones, etc.

Irregularities, Gusts or Puffs.—Though the wind at an altitude of 200 metres or more is comparatively steady, except in very rough or mountainous regions, near the surface of the earth any appreciable wind that may exist is always in a turmoil, owing to surface friction that checks the lower layer while the layers above tumble forward and down, and to numerous obstructing objects that block its course and introduce cross-currents. Hence its direction constantly changes through many degrees, while the velocity irregularly but persistently fluctuates from one extreme

to another. At one instant the actual velocity may be anything up to 50 per cent. or more greater than the average velocity, while a second or two later it may be fully 50 per cent. less than the average. The greater the average velocity the greater, roughly, in the same proportion, the absolute change, as illustrated by Fig. 29. So great, indeed, are these irregularities that places near the surface of the earth not more than 15 metres (50 feet) apart, though having the same average wind direction and velocity, commonly have different, often very different, simultaneous directions and velocities, and therefore, for the instant, radically different winds.

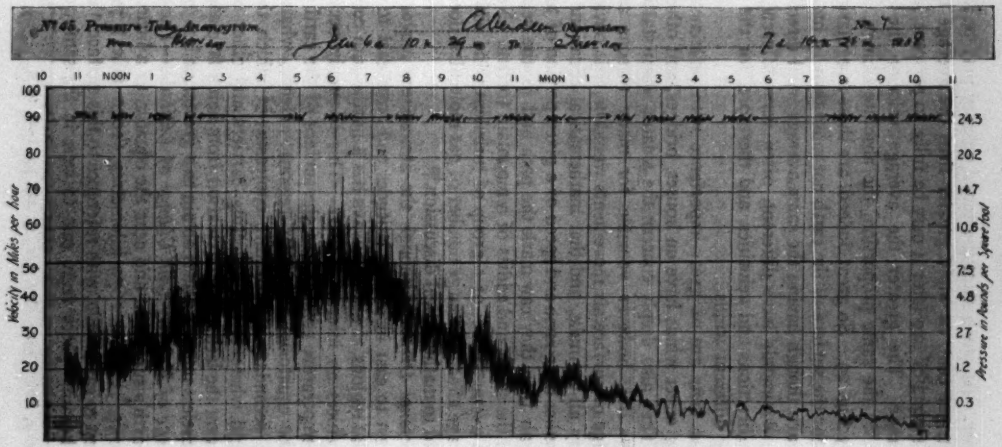
These facts are of great importance with reference to the wracking effect winds have on houses, bridges, and other structures. They also deeply concern the aviator when starting and landing. But, however valuable for many reasons an exact knowledge of surface air movements would be, it is obvious that they defy all formulæ, and that mathematical equations can no more predict the course and speed of a given portion of turbulent surface air than they can mark the path and fix the velocity of water in the swirls and eddies of a mountain torrent. Nevertheless, the average effect of a group of turbulent wind eddies, like the average effect of a large number of gas molecules, does profitably yield to mathematical discussion.[33]

Interzonal Drift.—Although the atmosphere moves mainly from west to east in middle latitudes and from east to west in equatorial regions, it nearly always has a north-south component that produces an interzonal drift. This is simply because the major temperature contrasts of the surface of the earth are between the equatorial and polar regions. Hence, whatever the local or secondary temperature contrasts, of which there are many, and whatever the deflecting barriers and other obstacles that prevent the latitudinal circulation from being free and rapid, it nevertheless must and does obtain to a greater or less extent.

Change of Velocity with Change of Latitude.—The velocity of the earth's surface at and near the equator, as a little calculation shows, is about 1675 kilometres (1040 miles) per hour from west to east, while, with reference to this surface, the velocity of the atmosphere from east to west in the same region is

[33] Taylor, *Phil. Trans. Roy. Soc.*, A, 215, pp. 1–26, 1915.

FIG. 29.



Irregularities in the surface wind velocity as indicated by a pressure-tube anemometer.

only a small fraction of this value. In reality, therefore, the atmosphere of equatorial regions is also moving from west to east with a great velocity, though not so great as that of the surface of the earth itself.

When this air moves to higher latitudes, as it does under the influence of the great temperature contrasts between equatorial and polar regions, it is obvious that its velocity with reference to the surface of the earth must change. It might seem, as many have assumed, that the linear velocity of the air would remain constant, and that the wind would have a west to east component as soon as it had crossed that latitude on which the surface velocity is the same as the original west to east wind movement. This method, however, of considering the problem is theoretically incorrect, as has often been explained. A particle of the atmosphere, or any portion of it moving as a unit, is mainly, at times wholly, rotating around the axis of the earth. In considering latitude effect, therefore, or effect of distance from this axis on wind velocity, it is necessary, as Ferrel first insisted, to remember that the angular momentum $mr^2\omega$ (in which m is the mass, r its distance from the axis of rotation, and ω the west-east angular velocity), and not the linear momentum mv (in which v is the west-east linear velocity), is a constant. In other words, the law of conservation of areas applies. Hence as a given mass of air reaches higher latitudes the absolute value of its east-west component tends, not to remain the same as is often supposed, but actually to become greater in proportion to the secant of the latitude. If the trend of the air is to lower latitudes, its west-east velocity obviously tends to get slower at the same rate that when going to higher latitudes it tends to become faster.

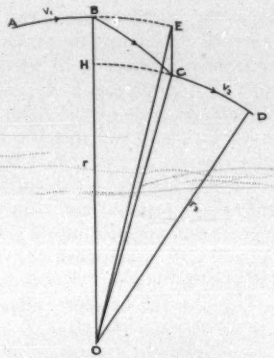
Law of Conservation of Areas.—The law of the conservation of areas as applied to the atmosphere is of sufficient importance to justify its brief demonstration.

Let O, Fig. 30, be the centre about which a mass m is moving with the linear velocity v_1 along the circular arc AB whose radius is r_1. Let m be constrained to follow its path by a central force; that is, a force directed towards O. For instance, let it move over a frictionless horizontal plane, and be kept in its orbit by the tension on a weightless string connecting it with the centre O. At B let the tension on the string be so increased that the mass m will be drawn in the distance BH in the same

time that, undisturbed, it would have reached E. During this time the path will be something like BC. If the tension again becomes constant with the value appropriate to the point C, the new orbital velocity will be v_2 along the arc CD of radius r_2.

By taking the time interval smaller and smaller the velocity along BH, however irregular, approaches uniformity as its limit, while BE and BC both approach straight lines. With the two component velocities along BE and BH respectively uniform it is obvious that the resultant velocity along BC must also be

FIG. 30.



Velocities along arcs of different radii.

uniform. The problem of vectorial areas reduces, therefore, to finding the general relation of a radius vector to the normal component thereto of the corresponding orbital velocity. This relation may be shown as follows:

Let BC, Fig. 31, be a rectilinear section of the orbit, usually of infinitesimal length, along which the velocity is uniform, and let OB and OC be two radii. From B draw BE perpendicular to OC extended, and from C draw CA perpendicular to OB. Hence

$$\frac{AC}{BE} = \frac{v_1}{v_2}$$

in which v_1 and v_2 are the components of the uniform velocity along BC at right angles to OB and OC, respectively. But

from the similarity of the triangles OAC and OEB it follows that

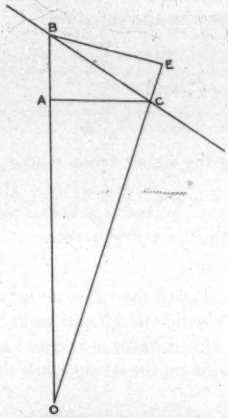
$$\frac{AC}{BE}=\frac{OC}{OB}$$

and, therefore, that

$$\frac{v_1}{v_2}=\frac{OC}{OB}$$

That is, $rv=k$, a constant, in which r is the radius vector and v the component of the orbital velocity at right angles thereto.

FIG. 31.



Conservation of areas in a plane.

But, by elementary geometry,

$$rv=2a,$$

in which a is the rate at which area is covered by the movement of r. Hence whatever the portion of the orbit, the radius vector sweeps over equal areas in equal intervals of time, or whatever the points selected,

$$\frac{v_1}{v_2}=\frac{r_2}{r_1}$$

The kinetic energy E_1 of the mass m while on the arc AB, Fig. 30, is given by the equation,

$$E_1=\tfrac{1}{2}mv_1^2.$$

Similarly, its kinetic energy along CD is given by

$$E_2 = \tfrac{1}{2}mv_2^2.$$

These are unequal, the difference being

$$\frac{m}{2}(v_2^2 - v_1^2),$$

and it will be interesting to find the source of inequality.

At all parts of the orbit the tension f on the string is given by the equation,

$$f = \frac{mv^2}{r}$$

and the work, dw, done on shortening the radius by the small amount dr is expressed by the equation,

$$dw = -\frac{mv^2}{r^2}\,dr.$$

But since $rv = k$, $v = \frac{k}{r}$, and

$$dw = -\frac{m\,k^2}{r^3}\,dr.$$

Hence on shortening the string from r_1 to r_2 the work becomes,

$$W = m\,k^2 \int_{r_2}^{r_1} \frac{dr}{r^3} = \frac{m}{2}\left(\frac{k^2}{r_2^2} - \frac{k^2}{r_1^2}\right).$$

But $k^2 = v^2r^2 = v_1^2\,r_1^2 = v_2^2r_2^2 =$ etc.

Hence $W = \frac{m}{2}(v_2^2 - v_1^2)$.

But this is identical with the value already found for the difference between the kinetic energies of m at the distances r_1 and r_2 from O. That is, this difference is equal and due to the work done on m by the tension on the string while decreasing the radius from r_1 to r_2.

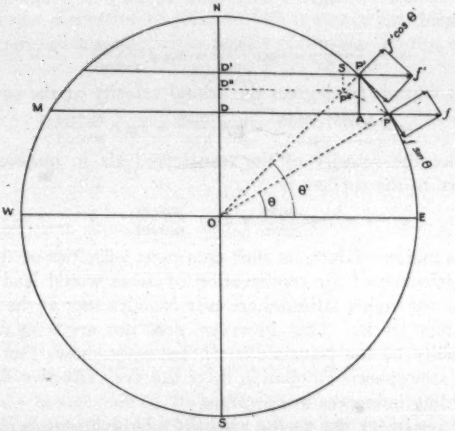
Consider now the velocity of a quantity of air or other mass moving as a unit frictionlessly over the surface of the earth. Let the mass m, regarded as a point (in the case of an extended body it is $\Sigma\, mvr$ that remains constant), be at P, Fig. 32, rotating around the axis NS on the small circle MP and held to the surface by gravity directed towards the centre O. If v is the linear velocity of m, it follows that the radially directed force f is expressed by the equation,

$$f = \frac{mv^2}{r} = \frac{mv^2}{DP}.$$

On forcing this mass to a higher latitude, to P', say, work is done against the horizontal component of f. But from the similarity of triangles it is obvious that at every point along the

arc PP', $f \sin \theta$, the force to overcome, is to f, the centrifugal force, as the rate of approach to the axis is to the rate of progress along the meridian. Thus the work done in going from P to P' is the same as that which would be done in shortening the radius DP to DA. But, as above explained, this work on m, or transfer of energy to it, must appear as so much additional kinetic energy, friction being excluded. Hence the orbital velocity v' at P' is to the orbital velocity v at P as DP is to $D'P'$. That is,

FIG. 32.



Conservation of areas on a sphere.

the conservation of areas holds likewise in this case, where the radius vector is the normal from the moving mass to the axis of rotation.

This same law holds also on the slightly flattened earth. To make this clear, let PP'' be a portion of a greatly flattened meridian, and let the mass m be taken from P to P' as before, and thence to P''. From P' to P'' the work is against the force $f' \cos \theta'$, and obviously equal to the work against f' over the distance $P'S$. Hence the orbital velocity of m at P'' is to its orbital velocity at P as DP is to $D''P''$.

Suppose a quantity of quiet air, air moving strictly with the surface of the earth, at, say, latitude 30 degrees, is forced to higher latitudes, as it actually is by pressure gradients due to temperature differences, what, according to the law of the conservation of areas, will be its final surface velocity at, say, latitude 60 degrees?

At latitude 30 degrees its orbital velocity, being the same as that of the surface, is, approximately,

$$v = \frac{2\pi 3957 \cos 30^\circ}{24} = 897.2 \frac{\text{miles}}{\text{hour}} = 401.1 \frac{\text{metres}}{\text{second}}.$$

At latitude 60 degrees its orbital velocity is, from the principle stated,

$$v' = v \frac{\cos 30^\circ}{\cos 60^\circ} = 1554 \frac{\text{miles}}{\text{hour}} = 694.7 \frac{\text{metres}}{\text{second}},$$

while at latitude 60 degrees the orbital velocity of the surface is

$$s = \frac{2\pi 3957 \cos 60^\circ}{24} = 518 \frac{\text{miles}}{\text{hour}} = 231.6 \frac{\text{metres}}{\text{second}}.$$

Hence the velocity of the transferred air in question with reference to the surface is

$$v' - s = 1036 \frac{\text{miles}}{\text{hour}} = 463.1 \frac{\text{metres}}{\text{second}}.$$

As a matter of fact, no such enormous velocities of the wind as the principle of the conservation of areas would lead one to expect in the higher latitudes are ever found, either at the surface or at other levels. This, however, does not argue against the applicability of the principle itself, but only shows that in the case of atmospheric circulation there are very effective damping or retarding influences in operation.

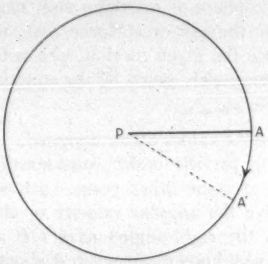
The resistance due to the viscosity of the atmosphere is one of these retarding influences, but its effect probably is very small. A larger effect doubtless comes from surface turbulence induced by trees, hills, and other irregularities. A still greater velocity control, probably so great that all others are nearly negligible in comparison, except near the surface, is vertical convection. This phenomenon leads to extensive interchange between lower and upper layers of the atmosphere, thus indirectly increasing the effect of surface friction probably several fold and tending to bring all the lower, vigorously convective, portion of the atmosphere to a common velocity. Because of these several means of control the actual wind velocity everywhere is different, and at high latitudes much less than it otherwise would be.

Not only is the velocity of the wind changed through change of latitude, but also the rate at which its direction with reference to the surface of the earth varies or tends to vary, as will appear from what follows.

Deflection Due to the Earth's Rotation.—The effects of the rotation of the earth on the direction of the wind are of extreme importance to the science of meteorology. It will be convenient, therefore, before going further, to consider how these important results are produced and to form some idea of their approximate magnitudes.

An exact discussion of this problem is somewhat tedious, but a very approximate solution is readily obtained. To this end, let

FIG. 33



Deflection, at pole, due to the earth's rotation.

P, Fig. 33, be one pole of the earth—the north pole, say—assume the surface to be flat, which it very approximately is, at and near this point, and let a particle of air cross it in the direction PA with the uniform velocity v; let the earth rotate in the direction AA' with the angular velocity ω, and let the distance which the air particle under consideration has gone from P in the brief time dt be such that

$$PA = dr = vdt.$$

Let the meridian along which the particle started as it left P have the position PA' at the end of the time dt, or when the particle, keeping a constant direction in space, has arrived at A. Obviously the velocity with which the earth moves under the particle increases directly with the distance from P. But as this latter is directly proportional to the time dt since the particle left

P, v being a constant, it is clear that the distance, travelled normally to the instantaneous meridian, ds, say, may be expressed in terms of a constant acceleration, a, in the direction opposite to that of rotation. That is,

$$ds = \tfrac{1}{2}\, a(dt)^2.$$

Also

$$ds = dr\ \omega\ dt = v\ dt\ \omega\ dt = v\ \omega\ (dt)^2.$$

Hence,

$$\tfrac{1}{2}\ a\ (dt)^2 = v\ \omega\ (dt)^2,$$

or

$$a = \omega\ v.$$

Since a force is measured in terms of mass times acceleration, it follows that the west-east deflective force, f, that would keep a mass m, of atmosphere or anything else, next the pole in the same meridian, or the east-west force that, if the earth were still, would produce the given motion with reference to its surface, is very approximately given by the equation,

$$f = ma = 2\ m\ \omega\ v,$$

where v and ω have the values above assigned.

Let the moving particle under consideration be not at one of the poles, but at some other point, such as P, Fig. 34, at latitude ϕ. Resolve the angular velocity ω, about ON, into its components about the right-angled axes OP and OP'. These components, as is well known, are $\omega \sin \phi$ about OP and $\omega \cos \phi$ about OP'.

Now all points on and exceedingly close to the equator of a rotating sphere have sensibly the same velocity, hence the direction and velocity of horizontally moving particles at P are affected by the component of rotation about OP only, and not at all by the component about OP'.

That is, at N, as already explained,

$$a = 2\ \omega\ v, \text{ and } f = 2\ m\ \omega\ v,$$

while at latitude ϕ, where the angular rotation is $\omega \sin \phi$,

$$a = 2\ \omega\ v \sin \phi, \text{ and } f = 2\ m\omega v \sin \phi,$$

to the right (going forward with the particle) in the northern hemisphere, to the left in the southern.

From this simple equation, assuming it to be exact, which it very nearly is, it follows that the deflective force due to the rota-

tion of the earth acting on a quantity of moving air (that is, the force that, assuming the earth to be still, measures the existing tendency of wind to change its direction with reference to any fixed line on the adjacent surface) is:

a. Directly proportional to its mass.

b. Directly proportional to its horizontal velocity.

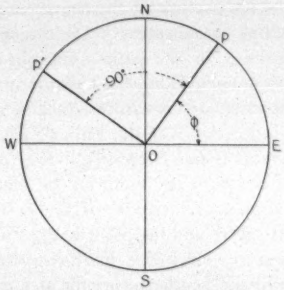
c. Directly proportional to the angular velocity of the earth's rotation.

d. Directly proportional to the sine of the latitude of its location.

e. Exactly the same whatever its horizontal direction.

f. Always at right angles to its instantaneous direction and

FIG. 34.



Deflection, away from pole, due to earth's rotation.

therefore wholly without influence on the velocity with reference to the surface.

g. Opposite to the direction of the earth's rotation. Hence to the right, or clockwise in the northern hemisphere; to the left, or counter-clockwise in the southern.

Since the deflection acceleration is all the time at right angles to the path, it follows that an object moving freely over the surface of the earth would describe an endless series of curves. At each point on this path the acceleration at right angles to it, measured with reference to the surface of the earth, is given, as explained, by the equation,

$$a = 2\,\omega\,v \sin \phi,$$

in which the terms have the values assigned above. It is also

given by the well-known equation for acceleration along a radius of curvature. That is,

$$a = \frac{v^2}{r},$$

in which, since the force is tangent to the earth, $r = R \tan \alpha$, where R is the radius of the earth, and α the angle subtended at the centre of the earth by the radius of the path at the point under consideration. Hence, when the only deflective influence is that due to the earth's rotation,

$$r = \frac{v}{2\omega \sin\varphi}, \text{ and } \tan\alpha = \frac{v}{2R\omega\sin\varphi}.$$

That is, the greater the linear velocity of the moving object over the surface of the earth, and the nearer it is to the equator, the greater the radius of curvature. On the equator the radius of curvature is infinite, or the path a straight line. However, unless the object is moving along the equator it soon gets to one side where the direction of curvature changes, as is well shown by the summer windtracks over the Indian Ocean.

Rate of Change of Wind Direction.—The theoretical rate of change of wind direction at any point on the surface of the earth obviously is the angular velocity ω' of the earth about an axis passing through its centre and the point in question. This change of direction, therefore, clockwise in the northern hemisphere, counter-clockwise in the southern, occurs at a rate *wholly independent* of wind velocity, and is given by the equation,

$$\omega' = \omega \sin \phi,$$

in which ϕ is the latitude of the place under consideration and ω the angular velocity about the axis through the north and south poles.

But, as the earth turns completely around during a sidereal day,

$\omega = \frac{2\pi}{86{,}164}$ per second = 15° 2′ 26″ per hour, or 15° per hour, roughly. Hence,

$\omega' = 15° \sin \phi$ per hour, roughly.

The approximate values of ω' corresponding to different latitudes may conveniently be tabulated as follows:

Earth Rotation in Degrees per Hour of Different Latitudes.

φ	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°
ω	0.00°	1.31°	2.60°	3.88°	5.13°	6.34°	7.50°	8.60°	9.64°	10.61°
φ	50°	55°	60°	65°	70°	75°	80°	85°	90°	
ω'	11.49°	12.29°	12.99°	13.59°	14.10°	14.49°	14.77°	14.94°	15.00°	

It must be clearly understood that the above values of rate of change of direction are based on the assumption that there is no friction and no disturbing horizontal pressure gradient, neither of which is true with reference to actual winds. Nevertheless, the values obtained are important, since they indicate the natural torque of the atmosphere, or its tendency to rotate when set in motion by pressure gradients.

It is interesting and quite practicable, as Whipple[34] has shown, to compute the path of a frictionless mass over the rotating earth when its direction and velocity are given for any definite point, but this will be omitted, since in the case of the actual atmosphere, because of viscosity, turbulence, surface obstacles, horizontal pressure gradients, etc., the departures from theoretical values are so great that it seems hardly necessary or even safe to go beyond the above simple and general relations.

Centrifugal Deflecting Force of Winds.—Usually the paths of winds are more or less curved, and therefore the moving air exhibits a "centrifugal force," or inertia force away from the centre of curvature in opposition to any applied "centripetal force." The value of this force, f, in the plane of the curve, not the plane of the horizon, is given by the equation,

$$f = \frac{mv^2}{r},$$

in which m is the mass concerned, v its linear velocity, and r the radius of curvature of the path at the place and time under consideration, or radius of the "small circle" in which the air is then moving.

Relative Values of Centrifugal and Rotational Components.—The ratio between the two deflective forces, rational and cen-

[34] *Phil. Mag.*, 33, p. 457, 1917.

trifugal (centrifugal action of the earth's rotation and centrifugal action due to curvature of path), varies greatly with the velocity of the wind, radius of curvature of its path, and latitude of its location. Within 20 degrees, at least, of the equator cyclonic storm winds commonly move on curves whose radii are comparatively small, 150 kilometres (93.2 miles) or less, in which case the centrifugal deflective force generally is greater than the rotational. In middle and higher latitudes, however, the average radii of cyclonic wind-paths usually are much larger, say 600 kilometres (373 miles), and the rotational deflective force greater than the centrifugal.

A few numerical examples will be interesting. No effort has been made to get average values, but only such as presumably often occur.

Ratios of Deflective Forces Under Given Conditions.

Latitude	Radius of curvature	Gradient velocity	$\frac{\text{Rotational force}}{\text{Centrifugal force}}$
	Miles	Miles per hour	
10°	20	80	1/44
20°	30	70	1/13
30°	100	50	10/19
40°	400	40	10/3
50°	400	35	14/3
60°	400	35	26/5

In tropical cyclones, therefore, the pressure gradient is balanced mainly by the centrifugal force, while in those of middle latitudes it is balanced chiefly by the rotational deflective force.

Ordinarily, except in the neighborhood of a well-marked low, the radius of curvature is much larger than any of the values above assumed, and consequently the ratio of rotation to centrifugal force correspondingly greater.

Total Horizontal Deflecting Force.—If the path of the air is at all curved, as it usually is, the total *horizontal* deflecting force, F, due to its velocity is given by the equation,

$$F = 2 m \omega v \sin \phi \pm \frac{mv^2}{r},$$

in which $r = r' \sec \alpha$, r' and α being the linear and angular radii (as seen from the centre of the earth) respectively of the "small circle" in which the air is moving, or $r = R \tan \alpha$, R being the

radius of the earth, and the other symbols have the meanings given above. The positive sign is used, or the deflective forces are additive, in the northern hemisphere when the course of the wind is counter-clockwise; in the southern hemisphere when the course is clockwise. The negative sign is used in each case when the sense of rotation is reversed. In cyclones, therefore, the total deflecting force is equal to the sum of the centrifugal and rotational deflective forces; in anticyclones to their difference.

When the winds become approximately steady the deflective force obviously is balanced against the gravitational pressure gradient. In symbols,

$$\frac{1}{\rho}\frac{dp}{dn} = 2\omega v \sin\phi \pm \frac{v^2}{r},$$

in which ρ is the density of the air, dp the slight difference between the pressures at the ends of the short horizontal distance dn at right angles to the path at the place considered. The meanings of the other symbols are given above. If the gradient is zero (that is, if the air moves without lateral restraint), $r = \frac{v}{2\omega \sin\phi}$, as previously shown, or $R \tan \alpha = \frac{v}{2\omega \sin\varphi}$; also, from the equation just given, $2\omega v \sin\phi \pm \frac{v^2}{r} = 0$. Hence, under the assumed conditions, $r = R \tan \alpha = \infty$; that is, $\alpha = 90°$, or the path is a great circle. However, these latter equations have but little more than a theoretical interest, since without the driving force of a pressure gradient wind velocity can neither be acquired nor (because of friction) maintained.

GRADIENT WIND.

Gradient Velocity.—That velocity of the air at which the deflective force due to the rotation of the earth and the centrifugal force jointly balance the horizontal pressure gradient is called the gradient velocity. It does not occur near the surface of the earth, owing to surface friction, but "from kite observations, it appears that at 1500 feet above the surface the agreement [between the observed and 'gradient' velocities] is generally very close," [35] especially in the absence of thunderstorms and other local disturbances. This does not mean that the wind has the same velocity at all levels beyond ½ kilometre, but only that above this height the velocity of an approximately steady wind

[35] Shaw, "Forecasting the Weather," p. 45.

is very nearly the gradient velocity appropriate to the atmospheric density, horizontal pressure gradient, and latitude at the place in question.

If the sense of rotation is that which exists in a cyclone, the two deflective forces are additive, as stated above, and the gradient velocity is given by the general equation,

$$v = \pm\sqrt{\frac{r}{\rho}\frac{dp}{dn} + (r\,\omega\sin\phi)^2} - r\,\omega\sin\phi, \quad . \quad . \quad . \quad . \quad . \quad (A)$$

in which the sign of the radical remains to be determined.

But obviously $v = 0$ when $\frac{dp}{dn} = 0$, as there can be no wind without a pressure gradient, from which it follows that the sign of the radical is positive, and that actually

$$v = \sqrt{\frac{r}{\rho}\frac{dp}{dn} + (r\,\omega\sin\phi)^2} - r\,\omega\sin\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad (B)$$

Theoretically this wind at any place is *along* the corresponding isobar, parallel, roughly, through the first one or two kilometres of elevation, to the surface isobar, and always in such direction that one moving with it will have the *lower* pressure to his *left*. It must be distinctly noted, however, that the above equations presuppose absence of friction and the attainment of a steady state. They therefore give the approximate wind velocity and direction only for levels above the appreciable reach of surface turbulence, and even there in the cases only of smooth and regular isobars. Near the surface where the velocity is checked by friction the wind direction is correspondingly deflected toward the region of lower pressure.

In the C. G. S. system of units:

v = centimetres per second.

$\frac{dp}{dn}$ = difference in dynes pressure per square centimetre, per centimetre horizontal distance at right angles to isobars. $r = r'$ sec α; r' = radius of curvature, in centimetres, of wind-path at time and place of observation, *not distance to the centre of the low;* α = angular radius, measured from the centre of the earth, of the "small circle" along which the wind is moving. Ordinarily r differs from r' by less than 1 part per 100, and therefore, in practice, they may be assumed to have equal values.

ρ = grammes of air per cubic centimetre.

ω = angle through which the earth turns per second, $\frac{2\pi}{86{,}164}$.

$\sin \phi$ = natural sine of the angle of latitude.

If the path of the wind is straight (that is, if there is no centrifugal force), the equation for gradient velocity is

$$v = \frac{\frac{dp}{dn}}{2\omega\rho \sin \varphi}.$$

In anticyclonic regions gradient winds, as explained, obey the equation,

$$\frac{1}{\rho}\frac{dp}{dn} = 2\omega v \sin\phi - \frac{v^2}{r},$$

or,

$$v = r\omega \sin \phi \pm \sqrt{(r\omega \sin \phi)^2 - \frac{r}{\rho}\frac{dp}{dn}} \quad \ldots\ldots\ldots (C)$$

As above,

$$v = 0 \text{ when } \frac{dp}{dn} = 0.$$

Hence, in this case, the sign of the radical is negative and

$$v = r\omega \sin \phi - \sqrt{(r\omega \sin \phi)^2 - \frac{r}{\rho}\frac{dp}{dn}} \quad \ldots\ldots\ldots\ldots\ldots (D)$$

Obviously, then, as pointed out by Gold,[36] steady anticyclonic winds cannot become intense, since the maximum possible velocity is given by the equation,

$$v \max = r\omega \sin \phi.$$

For example, if $r = 500$ kilometres, and $\phi = 40°$,

$$v \max = 23.4 \text{ metres per second} = 52.3 \text{ miles per hour.}$$

The gradient that produces this velocity is given by the equation,

$$\frac{dp}{dn} = \rho r (\omega \sin \phi)^2.$$

On substituting this gradient in the equation above for straight winds, it appears that it would give the velocity,

$$v = \frac{\rho r (\omega \sin \phi)^2}{2\rho\omega \sin \phi} = \tfrac{1}{2} r \omega \sin \phi.$$

That is, the limiting velocity of anticyclonic winds,

$$v \max = r\omega \sin \phi,$$

[36] M. O., No. 190, "Barometric Gradient and Wind Force," London, 1908.

is just twice that which the corresponding pressure gradient would give to straight winds.

Since " for the time being, we may regard the gradient winds as the best estimate we can give of the actual winds at, say, 1500 feet above the surface," [37] it seemed advisable to construct tables (see Appendix), one for cyclonic, the other for anticyclonic conditions, that give the theoretical wind velocities in metres per second, kilometres per hour, and miles per hour for various latitudes, radii of curvature, and pressure gradients, as indicated, each to be used in conjunction, of course, with the current weather map, corrected, if need be, by estimation or by special reports, for the hours that have elapsed since the observations were made from which it was constructed.

As the equations demand and the tables indicate, the winds of an anticyclone, gradient for gradient, latitude for latitude, and curvature for curvature, are stronger, often much stronger, than those of a cyclone. This may seem to be flatly contradicted by the fact that anticyclones are characterized by relatively light winds, but the contradiction is only apparent, for, as the equations show, steep gradients cannot obtain in anticyclonic regions, nor, therefore, heavy winds except near their borders, or when r is large. However, in general, strong anticyclonic winds cover only a narrow strip of territory, and their duration, therefore, is comparatively brief.

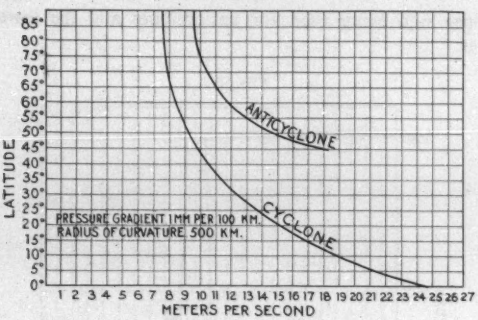
Figs. 35, 36, and 37 represent respectively the effect of latitude, pressure gradient, and radius of curvature on the " gradient " velocity, other things in each case being constant.

Surface gradients and surface isobars, when well defined and in the absence of local disturbances, may be used for approximate values up to elevations of, roughly, two kilometres, except wherever the horizontal temperature gradient is steep and opposite in direction to the horizontal pressure gradient. In such cases the temperature tends to weaken and finally reverse the pressure gradient with increase of elevation. Hence, since the temperature gradient is nearly always more or less poleward, in extra-tropical regions the east wind generally is the shallowest and the least likely to have, at an elevation of two kilometres, say, the direction and velocity computed from the surface system of isobars; and

[37] Shaw, " Forecasting the Weather," p. 49.

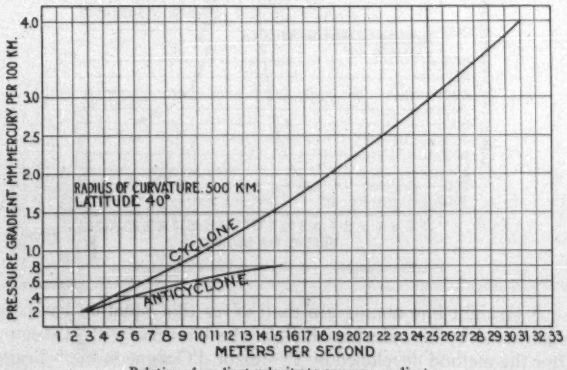
the west wind the deepest, with direction and velocity closest in agreement with the values thus computed. In short, with increase of elevation the isobars, usually closed on the surface, tend to

FIG. 35.



Relation of gradient velocity to latitude.

FIG. 36.



Relation of gradient velocity to pressure gradient.

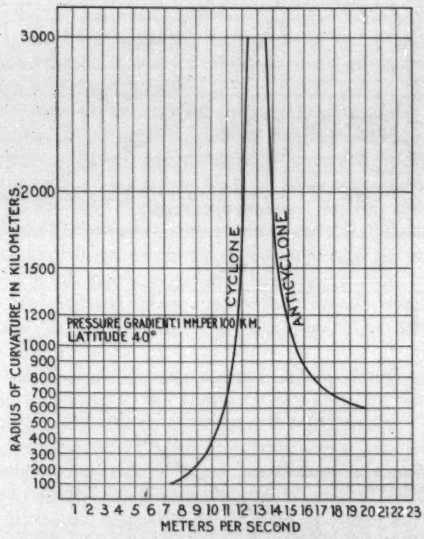
open out and roughly to follow the parallels of latitude with the decrease of pressure, at least to well above the troposphere, directed poleward.

Gradient Velocity Nomogram.—The general gradient velocity equation, $F = 2 m \omega v \sin\phi \pm \frac{mv^2}{r}$, reduces, on dividing by m, to

$$2 \omega v \sin \phi - \frac{1}{\rho} \frac{dp}{dn} = \pm \frac{v^2}{r},$$

the upper sign being used for anticyclones and the lower for cyclones.

FIG. 37.



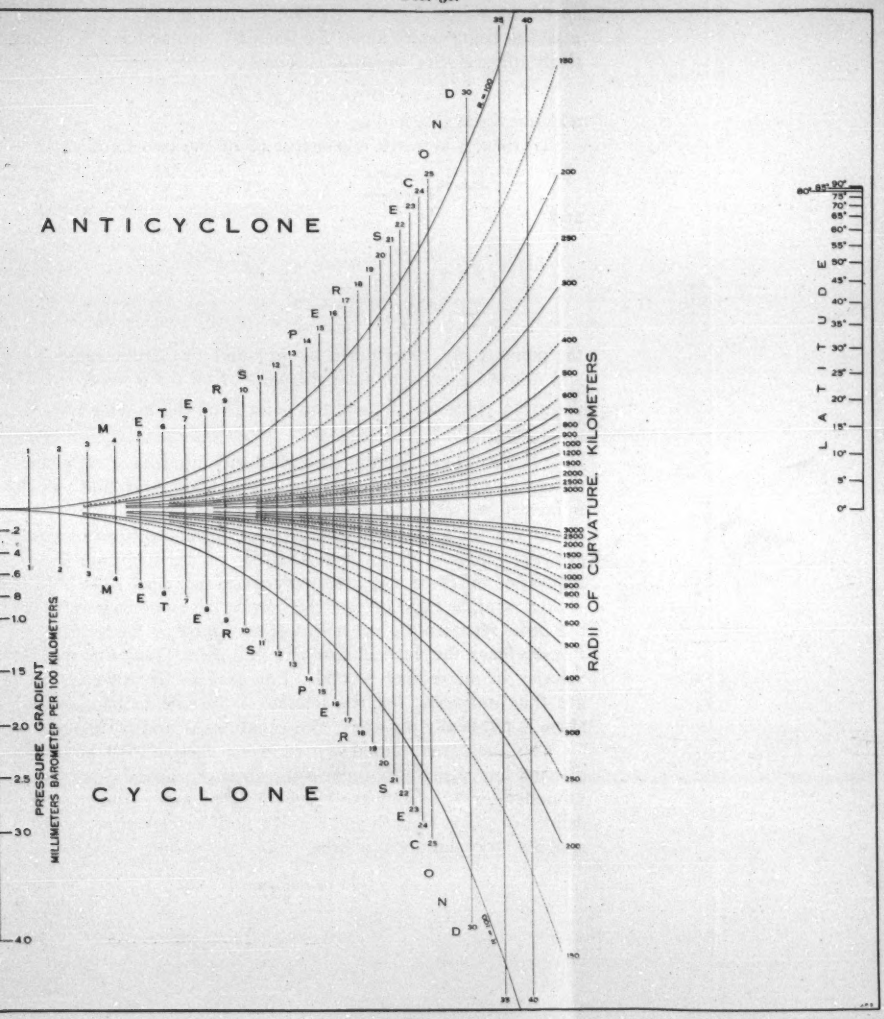
Relation of gradient velocity to radius of curvature.

A straight line nomogram that solves this equation has been constructed by Mr. Herbert Bell, of the University of Michigan, after the method developed by Professor d'Ocagne in his "Traité de Nomographie." The solution is as follows:

Writing

$$u = -\frac{20}{\rho} \frac{dp}{dn}, \text{ and } w = 10^3 \omega \sin \phi,$$

FIG. 38.



Gradient velocity nomogram.

u and w being scales along the lines $x = -10$ and $x = 10$ respectively, the velocity equation becomes

$$2500\,u + v\,w = \pm 50{,}000\,\frac{v^2}{r}$$

which is linear in u and w.

If, then, a network is constructed of the two families

$$x = 10\,\frac{v - 2500}{v + 2500} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

and

$$y = \pm \frac{50{,}000\,\frac{v^2}{r}}{v + 2500}$$

$$= \pm \frac{6.25 \times 10^4}{r}\,\frac{(10 + x)^2}{10 - x} \quad \ldots\ldots\ldots \quad (2)$$

the point c, say, determined by (1) and (2) from values of v and r, will be collinear with the point A on the u scale, fixed by the given value of $\frac{dp}{dn}$, and the point B on the w scale indicated by the latitude.

The resulting diagram, with gradients in terms of millimetres difference of barometer reading per 100 kilometres, and velocity in metres per second, is given in Fig. 38.

To find the gradient wind velocity, connect the known pressure gradient (marked on lower left border of the diagram) and the latitude of the place in question (given on the upper right border) with a straight edge or stretched string and note where it cuts the curve representing the radius of curvature of the local isobar. For *cyclones* the vertical through this point gives the required velocity in metres per second. For *anticyclones* two velocities are thus indicated, but the *smaller* is the one to take, since it alone is physically possible. See equations *C* and *D*, above.

This nomogram should be used in conjunction with the surface distribution of pressure only in the absence of local disturbances (thunderstorms, squalls, etc.); where the pressure gradient is well defined—isobars smooth and regular, and for elevations between, roughly, 500 and 2000 metres.

(*To be continued.*)

EXPERIMENTAL TEST OF THE WIEDEMANN-FRANZ RATIO THROUGH A CHANGE OF STATE.*

BY

EDWIN F. NORTHRUP, Ph.D.,

Palmer Physical Laboratory, Princeton, N. J.,
Member of the Institute,

AND

FRANK R. PRATT.

THE best conductors of electricity are, in general, the best conductors of heat. The ratio of the thermal to the electrical conductivity for all pure metals at the same temperature has nearly the same value when the temperature is in the neighborhood of 20° C. The value of this ratio is assumed to be proportional to the absolute temperature.

If we call k thermal conductivity, σ the electrical conductivity, a the universal gas-constant, e the electrical charge carried by a univalent electrolytic ion, and T the absolute temperature, then the law, which has long been known as the result of observations and generally called the Wiedemann-Franz law, states that

$$\frac{k}{\sigma} = \frac{4}{3}\left(\frac{a}{e}\right)^2 T = 0.715 \times 10^{-10} \text{ at } 18° \text{ C.}^1$$

This law holds remarkably well for pure metals, less accurately for alloys, and not at all for poor conductors. How well it holds for the pure metals is exhibited in the table on page 68 of Campbell (see reference below). In this table the observed value given for silver is 0.76×10^{-10} and for bismuth 1.068×10^{-10} both at 18° C. Considering the large discrepancy in the resistance values for silver and bismuth, the closeness between these numerical values is very good, and the agreement between both values and the value obtained above for the ratio, obtained upon the basis of pure theory, is quite surprising.

The writers believe that any law which is based upon purely theoretical considerations can only be expected to hold over a comparatively limited range of variation of the magnitudes mutually related by the law. If the law can be shown experimentally to continue to hold when some one of the magnitudes,

* Communicated by Dr. Northrup.

[1] Consult Campbell, "Modern Electrical Theory," 1913 ed., pp. 66-68.

as the temperature, is varied through a wide range, then its usefulness and universality are both extended.

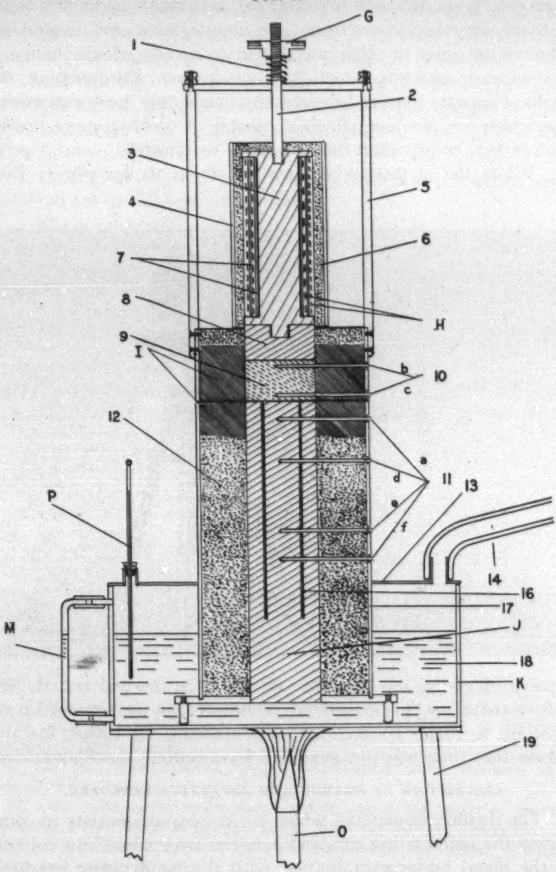
The object of the present investigation was to determine experimentally if the Wiedemann-Franz ratio continues to hold approximately true for two typical metals which change in resistance in opposite directions when these are carried from the solid into the molten condition. The two metals chosen for study were tin and bismuth, because both of these metals have low melting-points and both have been very carefully investigated by the first-named writer in respect to their resistivity characteristics.[2] Thus, the ratio of the electrical resistivity just after fusion (47.4 microhms) to its resistivity just before fusion (22.0 microhms) is 2.154 for the metal tin. Similar figures for the metal bismuth are 267 microhms just before fusion and 127.5 microhms just after fusion, the ratio of the latter to the former being 0.477. For the Wiedemann-Franz ratio to hold for these two metals, when carried from the solid into the molten state, their thermal resistivities or thermal conductivities must likewise change in an abrupt manner and in an opposite direction for each of the two metals.

The investigation which we proceed to describe is not a first attempt to obtain information on this matter. After the present investigation was started an article was found in *The Physical Society of London Proceedings*, vol xxvii, part iv, June 15, 1915, p. 307, on "The Change in Thermal Conductivity of Metals on Fusion," by Alfred W. Porter, D.Sc., F.R.S., and F. Simeon, B.Sc., research scholar University College of London. Sodium and mercury were examined by these writers, using a method radically different from the one employed by us. Metals were placed in a glass tube, the portion in the upper half of the tube being maintained molten and the portion in the lower half of the tube being maintained solid. The ratio required was obtained by comparing the slopes of the tangents to the temperature gradient curves for the molten and the solid portions of each metal.

The results obtained seemed to indicate quite conclusively that the Wiedemann-Franz ratio holds over a change of state

[2] "Resistivity of a Few Metals Through a Wide Range of Temperature," by Edwin F. Northrup and V. A. Suydam, JOURNAL OF THE FRANKLIN INSTITUTE, February, 1913.

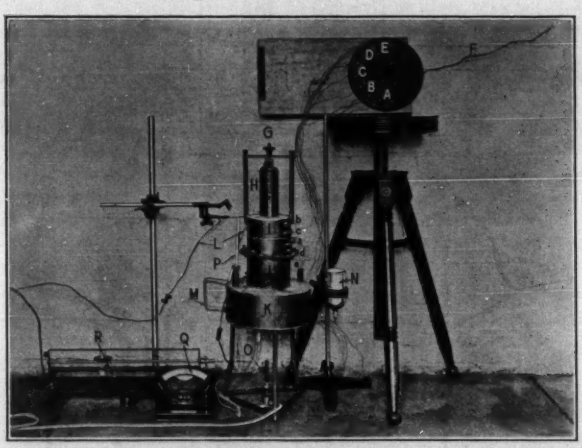
FIG. 1.



in the cases of these two metals. However, as sodium and mercury both *increase* in electrical resistance upon fusion, it seemed desirable to continue our investigation and extend the inquiry not only to other metals but to metals which change in resistance in opposite directions upon fusion. Furthermore, our method appears to us to be one which is not only more extensively applicable but also one which is capable of yielding more precise and certain results than the one above referred to.

While the method which we are about to describe is fully

FIG. 2.



capable of giving the absolute values of the thermal resistivities before and after fusion, we only attempted, in the present investigation, to make an accurate determination of ratios for the reason that time was not available for anything more extensive.

DESCRIPTION OF METHOD AND APPARATUS EMPLOYED.

The method in general, which we employed, consists in comparing the temperature gradient between two points in a column of the metal under examination with the temperature gradient between two points of a cylinder of cold-rolled steel shafting. The arrangement provided gave assurance that the quantity of

heat flowing per square centimetre between the two temperature-points in the metal being measured and between the two temperature-points in the steel cylinder was nearly the same, and that the heat flow was steady at the time of taking an observation. A full understanding of the method may be best obtained by a careful inspection of the cross-sectional view of the apparatus employed shown in Fig. 1 and the photographic view of the apparatus shown in Fig. 2.

Referring to Fig. 1, various parts which are lettered and numbered are as follows:

1. Spring which allows the metal to expand and contract.
2. Rod supporting heater.
3. Copper cylinder which conducts heat to the metal.
4. Brass casing surrounding heater.
5. Brass frame supporting heater.
6. Kieselguhr heat insulator.
7. Mica insulating sheets.
8. Upper steel cylinder.
9. Metal to be tested.
10. Thermo-elements in metal to be tested.
11. Thermo-elements in lower steel cylinder.
12. Kieselguhr heat insulator.
13. Cover to pan containing boiling water.
14. Rubber hose for conducting steam away from apparatus.
16. Fibrox heat insulator.
17. Brass casing surrounding lower steel cylinder and insulation.
18. Water at 100° C.
19. Supporting tripod.

G, H, I, J, K, M, O, P, a, b, c, d, e, see description of Fig. 2.

Referring to the photograph of the apparatus, Fig. 2, the various lettered parts are as described below.

A, B, C, D, E, a switch for shifting the lead wires *F* to any pair of wires coming from the several thermo-elements *a, b, c, d, e*. There are two binding posts near each letter. Lead wires *F* are connected to the two posts near *C* in the figure.

F, two lead wires running to the potentiometer which measures the potential of the several thermocouples.

G, screw with spring underneath, used to adjust the height of heater *H*. Spring allows heater to rise and fall as metal expands and contracts.

H, electric heater, insulated nichrome wire wound on copper cylinder and covered with brass case.

I, hollow alberene stone cylinder. Hollow part contains the metal to be tested, the upper steel cylinder and two thermocouples, *b* and *c*. Brass casing on the outside.

J contains the lower cylinder of steel. Between this cylinder and the outer brass casing is the kieselguhr heat insulator. This lower steel cylinder contains the thermocouples, *a* and *d*, for measuring the heat gradient in the steel; also an extra thermocouple, *e*, much lower down to test for loss of heat.

K, lower pan containing boiling water.
L, leads carrying direct electric current to heater *H*.
M, glass water gauge showing height of water in pan *K*.
N, Dewar bulb containing ice and thermocouples.
O, Bunsen burner for keeping water in *K* at the boiling-point.
P, thermometer for reading the temperature of water in *K*.
Q, Ammeter for measuring the current passing through heater *H*.
R, Rheostat for controlling current in heater *H*.

Dimensions of Heat-Resistance Apparatus.

Outside diameter of steel guard ring, *J*	5.08 cm.
Inside diameter of steel guard ring, *J*	2.54 cm.
Outside diameter of centre steel rod	1.80 cm.
Length of lower steel cylinder, *J*	21.59 cm.
Length of upper steel cylinder, 8	2.08 cm.
Length of copper heater, 3	12.70 cm.
Diameter of outside brass shell	12.70 cm.
Diameter of lower pan, *K*	25.40 cm.
Diameter of hole for thermocouple in guard ring	0.25 cm.
Diameter of hole for thermocouple in steel rod	0.19 cm.
Distance from top of lower cylinder to upper hole	1.00 cm.
Distance from upper hole to next hole	3.00 cm.
Distance between thermocouples in steel rod	3.00 cm.
Distance between thermocouples in metal used	2.00 cm.
Length of nichrome wire in heater, about	610.00 cm.
Width of nichrome wire in heater	.16 cm.
Thickness of wire in heater, No. 31 B. & S.	
Resistance of heating coil	12.95 ohms
Height of lower pan	10.16 cm.

DATA OBTAINED.

As the reliability and accuracy of the results obtained in this investigation are wholly determined by the consistency and reproducibility shown in the readings taken, we give below in tabulated form the various series of observations just as they were made.

Capital letters, *A*, *B*, *C*, *D*, refer to the lettered studs on the thermocouple switch (see Fig. 2). Small letters, *a*, *b*, *c*, *d*, refer to the corresponding thermocouples (see Fig. 1). Numerals refer to the number of the observation taken under a given set of conditions.

Results obtained for the metal tin follow below:

TIN (Solid).

May 16, 1915

Microvolts No.	A	B	Current, 4.5 ampères C	D
1	7618	9481	9205	638
2	7623	9497	9230	645
3	7650	9520	9247	645
4	7655	9533	9248	641

Temperatures computed from above data and thermal resistance compared to steel:

No.	a	b	c	d	Resistance
1	168.08	203.68	198.49	155.55	0.62
2	168.18	203.98	198.96	155.52	0.60
3	168.71	204.41	199.28	156.05	0.61
4	168.80	204.66	199.30	156.23	0.64

Average temperature of tin ..... 202° C.
Average temperature of steel 162
Average resistance compared with steel..... 0.62

Microvolts No.	A	B	Current, 4.5 ampères C	D
1	7722	9616	9330	660
2	7729	9618	9330	658
3	7728	9618	9335	655
4	7730	9620	9333	653

Temperatures computed from above data and thermal resistance compared to steel.

No.	a	b	c	d	Resistance
1	170.11	206.21	200.84	157.17	0.62
2	170.24	206.25	200.84	157.35	0.63
3	170.22	206.25	200.94	157.39	0.64
4	170.26	206.28	200.90	157.47	0.65

Average temperature of tin ..... 204° C.
Average temperature of steel 164
Average resistance compared with steel..... 0.63

Microvolts No.	A	B	Current, 4.7 ampères C	D
1	8137	10500	10034	783
2	8192	10538	10072	778
3	8230	10572	10091	783

Temperatures computed from above data and thermal resistance compared to steel.

No.	a	b	c	d	Resistance
1	178.13	222.59	213.99	162.92	.85
2	179.19	223.29	214.69	164.09	.86
3	179.94	223.91	215.04	164.80	.88

Average temperature of tin ..... 219° C.
Average temperature of steel 172
Average resistance compared with steel..... 0.86

TIN (Solid)—*Continued.*

Microvolts No.	A	B	Current, 4.7 ampères C	D
1	8443	10733	10197	810
2	8460	10748	10200	810
3	8470	10757	10205	805
4	8475	10751	10203	805
5	8480	10752	10204	805
6	8488	10759	10202	810

Temperatures computed from above data and thermal resistance compared to steel.

No.	a	b	c	d	Resistance
1	184.02	226.86	217.00	168.37	.94
2	184.35	227.14	217.06	168.71	.97
3	184.54	227.30	217.15	169.00	.98
4	184.63	227.19	217.12	169.10	.96
5	184.73	227.21	217.13	169.19	.97
6	184.88	227.34	217.10	169.23	.98

Average temperature of tin ..... 222° C.
Average temperature of steel 177
Average resistance compared with steel..... 0.97

TIN (Molten).

Microvolts No.	A	B	Currents, 5 ampères C	D
1	11628	14705	12680	1495
2	11937	14907	12903	1497
3	11991	15050	12962	1517
4	12026	15100	13022	1518
5	12103	15154	13092	1525
6	12134	15160	13140	1510
7	12152	15190	13146	1507
8	12185	15245	13196	1533
9	12210	15268	13205	1524
10	12226	15275	13218	1508
11	12228	15260	13222	1520
12	12227	15272	13212	1529
13	12238	15287	13223	1522

Temperatures computed from above data and thermal resistance compared to steel.

No.	a	b	c	d	Resistance
1	243.13	297.35	261.94	215.76	1.94
2	248.70	300.85	265.88	221.49	1.90
3	249.67	303.28	266.93	222.11	1.98
4	250.29	304.14	268.99	222.74	1.91
5	251.66	305.07	269.22	224.03	1.95
6	252.22	305.17	270.06	224.87	1.93
7	252.52	305.69	270.17	225.25	1.96
8	253.13	306.62	270.29	225.38	1.96

TIN (Molten)—*Continued.*

No.	*a*	*b*	*c*	*d*	Resistance
9	253.58	307.01	271.21	226.00	1.95
10	253.86	307.13	271.44	226.59	1.95
11	253.90	306.88	271.51	226.41	1.93
12	253.88	307.08	271.33	226.23	1.93
13	254.08	307.34	271.52	226.55	1.95

Average temperature of tin ..... 285° C.
Average temperature of steel 235
Average resistance compared with steel..... 1.94

May 9, 1916
Current, 5.9 ampères

Microvolts *No.*	*A*	*B*	*C*	*D*
1	12238	15305	13232	1527
2	12247	15310	13243	1512
3	12248	15303	13227	1530
4	12243	15330	13240	1520
5	12243	15284	13235	1532
Average	12243	15306	13239	1524

Computed temperatures in ° C. from above data.

a	*b*	*c*	*d*
254.17	307.66	271.81	226.61

Average temperature of tin ..... 290° C.
Average temperature of steel 240
Average resistance compared with steel..... 1.95

May 16, 1916
Current, 6.5 ampères

Microvolts *No.*	*A*	*B*	*C*	*D*
1	12937	16420	14212	1738
2	12968	16450	14248	1737
3	12990	16475	14293	1743

Computed temperatures and thermal resistances compared to steel.

Temperatures *No.*	*a*	*b*	*c*	*d*	Resistance
1	266.52	326.60	288.82	235.36	1.82
2	267.10	327.11	289.46	235.94	1.81
3	267.51	327.53	289.90	236.24	1.81

Average temperature of tin ..... 308° C.
Average temperature of steel 252
Average resistance compared with steel..... 1.81

Current, 6.5 ampères

Microvolts *No.*	*A*	*B*	*C*	*D*
1	13032	16478	14309	1737
2	13040	16462	14305	1722
3	13044	16450	14314	1718
4	13050	16468	14323	1719

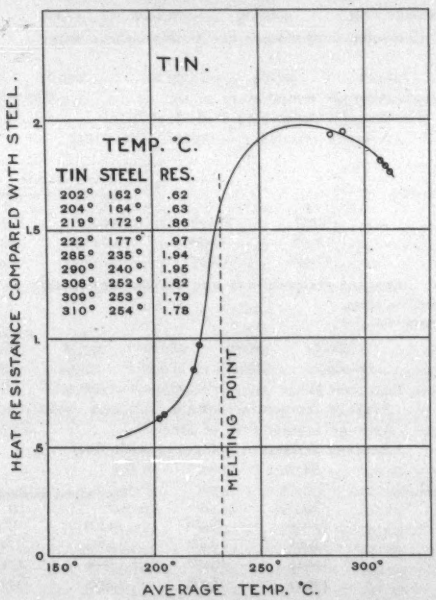
TIN (Molten)—*Continued.*

Temperatures No.	a	b	c	Thermal resistance d	Resistance
1	268.16	327.58	290.51	237.11	1.79
2	268.30	327.31	290.44	237.53	1.80
3	268.37	327.11	290.59	237.67	1.79
4	268.47	327.41	290.75	237.76	1.79

Average temperature of tin ..... 309° C.
Average temperature of steel 253
Average resistance compared with steel..... 1.79

Microvolts No.	A	B	Current, 6.5 ampères C	D
1	13057	16482	14342	1727
2	13074	16480	14340	1720
3	13072	16470	14332	1720

FIG. 3.



TIN (Molten)—*Continued.*

No.	Temperatures a	b	c	Thermal Resistance d	Res.
1	268.60	327.65	291.08	237.74	1.78
2	268.90	327.61	291.04	238.18	1.78
3	268.87	327.44	290.90	238.14	1.78

Average temperature of tin..... 310° C.
Average temperature of steel..... 254
Average resistance compared with steel.. 1.78

The results of these observations are summarized and embodied in the curve for tin, Fig. 3.

A series of observations obtained for the metal bismuth are presented in the following tabulations:

BISMUTH (Solid).

May 30, 1916

Microvolts by potentiometer No.	A	B	Current, 4 ampères C	D
1	5923	9207	7325	327
2	5928	9220	7348	333
3	5940	9230	7350	332
4	5949	9230	7344	330
5	5950	9232	7350	332

Computed temperatures for each No. and resistance (thermal) compared with steel.

No.	a	b	c	d	Resistance
1	134.35	198.59	162.34	140.97	8.20
2	134.45	198.78	162.79	141.19	8.00
3	134.69	198.96	162.83	141.41	8.07
4	134.87	198.96	162.71	141.56	8.13
5	134.89	199.00	162.84	141.62	8.07

Average temperature of bismuth..... 180.69° C.
Average temperature of steel..... 137.96
Average resistance compared with steel 8.09

Microvolts No.	A	B	Current, 4.5 ampères C	D
1	6602	11537	8779	470
2	6618	11552	8813	470
3	6627	11567	8828	470
4	6634	11594	8827	475
5	6650	11614	8844	480

Computed temperatures in ° C. for each No. and thermal resistance compared with steel.

No.	a	b	c	d	Resistance
1	148.04	241.49	190.43	157.37	8.21
2	148.36	241.76	191.08	157.68	8.15
3	148.56	242.03	191.36	157.86	8.17
4	148.68	242.52	191.34	158.09	8.21
5	149.00	242.88	191.67	158.51	8.38

Average temperature of bismuth ..... 216.62° C.
Average temperature of steel ..... 153.23° C.
Average resistance compared with steel.. 8.22

BISMUTH (Molten)—*Continued.*

Microvolts — Current, 4.8 ampères

No.	A	B	C	D
1	7213	12873	9738	640
2	7227	12888	9743	644
3	7244	12883	9754	602
4	7257	12870	9767	603
5	7266	12875	9768	597

No.	a	b	c	d	Resistance
1	160.15	265.35	208.49	172.65	6.82
2	160.42	265.62	208.58	172.99	6.81
3	160.76	265.53	208.79	172.51	7.21
4	161.01	265.30	209.03	172.78	7.18
5	161.19	265.39	209.05	172.84	7.26

Average temperature of bismuth..... 237.13°C.
Average temperature of steel..... 166.67
Average resistance compared with steel.. 7.06

Microvolts by potentiometer. — May 23, 1916 — Current, 5.9 ampères

Thermocouples	A	B	C	D
	9685	17363	13326	1248
No. 1	9885	17395	13352	1260
	10075	17110	13258	1235
	11620	17097	13250	1230
Average	10316	17241	13297	1243
No. 2	10034	17067	13230	1215
	10040	17045	13210	1210
Average	10037	17056	13220	1212
No. 3	10392	17143	13307	1227
	10383	17116	13290	1220
	10389	17127	13285	1224
	10382	17132	13298	1225
	10390	17145	13292	1230
	10384	17156	13300	1228
	10400	17158	13300	1230
	10398	17155	13300	1230
Average	10390	17141	13297	1227

Computed temperatures in ° C., using average potential:

	a	b	c	d
No. 1	219.20	340.41	272.83	196.00
No. 2	214.04	337.30	271.47	191.30
No. 3	220.57	338.73	272.83	197.70

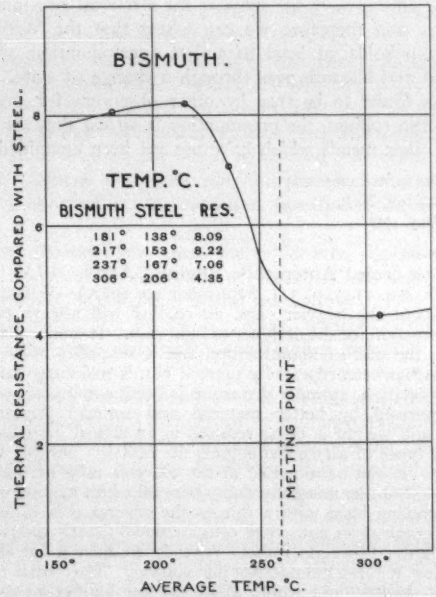
Average temperatures of the bismuth and steel between thermocouples. Thermal resistance compared to steel.

BISMUTH (Molten)—*Continued.*

	No. 1	No. 2	No. 3	Average
Bismuth temperature	306.62	304.36	305.78	305.59
Steel temperature	207.60	202.67	209.13	206.70
Resistance	4.37	4.35	4.33	4.35

These average values at the right give the only point found for molten bismuth. No point closer to the melting-point could have been found, because the melting-point of bismuth is 269° C., and the cooler thermocouple *c* registers only 272°, which shows

FIG. 4.



that the cooler part of the bismuth was just above the melting-point. No point at a higher temperature could be found, because the nichrome wire used in the heater was at a bright red heat to obtain the above. Any higher temperature would have melted the wire.

The curve for bismuth (Fig. 4) summarizes and embodies the observations given in the above tabulations.

A detailed description of the many precautions and arrangements employed to insure accuracy would be beyond the limits of our space for this article, but we can assure those interested that all the observations were taken with extreme care, and we feel certain that no errors of any considerable magnitude have crept into the observations. The conclusion, therefore, is inevitable that the thermal resistance characteristics for both tin and bismuth, when these metals pass from the solid into the molten state, are substantially the same as the electrical resistance characteristics, and therefore we can assert that the Wiedemann-Franz ratio holds, at least to a first approximation, when the metals tin and bismuth pass through a change of state. As the same was found to be true by other observers for the metals mercury and sodium, the presumption is strong that the same is true for other metals which have not yet been examined.

PALMER PHYSICAL LABORATORY,
PRINCETON, N. J.,
May, 1917.

The Air-cooled Automobile Engine. ANON. (*The Autocar*, vol. xxxix, No. 1145, p. 311, September 29, 1917.)—Whatever may be said about the heavier cars, air-cooling will always possess a special attraction for the designer of light cars. It diminishes weight, it reduces the cost of manufacture, and it simplifies upkeep. Air-cooling, as has been repeatedly pointed out, is making great strides, thanks to aviation; cylinder distortion is being eliminated; cooling is being improved by better material and sounder constructional methods, and weight is being reduced in an almost incredible ratio.

Of all types of air-cooled engine, the radial is possibly the most attractive. It can be mounted at the extreme nose of the chassis, where it will not be unsightly and where all of its cylinders will get an even cooling blast with a fan on the reverse side if necessary. Its short crank-shaft and other constructional details endow it with amazing power-to-weight ratios. Already we have a flat air-cooled twin engine at three pounds per horsepower. The radial engine is extremely shallow, and would allow the car builder an extra two feet of space along the chassis. There is no need for the large number of cylinders used in air propulsion to secure a satisfactory balance. A 20-horsepower, 800-pound vehicle is probably practicable. The type is perhaps suited only to comparatively low horsepowers, as the crank-shaft centre would come too high up if the cylinder were at all large.

THE DETERIORATING ACTION OF SALT AND BRINE ON REINFORCED CONCRETE.*

BY

HENRY JERMAIN MAUDE CREIGHTON,

Department of Chemistry, Swarthmore College.
Member of the Institute.

At the present time, when concrete structures are being erected throughout the country for all manner of purposes, it is of the greatest importance that the limitations, the durability, and the causes of the deterioration of reinforced concrete should be thoroughly understood. Within the past few years the number of reinforced concrete structures has been increasing so rapidly that to-day concrete has replaced brick and stone to a large extent. Since most of our oldest reinforced concrete is not over fifteen to eighteen years old, who can predict, from so short a period of observation, its condition twenty-five or fifty years hence?

During the past few years there has been considerable discussion regarding the durability of concrete, and there exists a certain amount of disagreement on the matter. There appeared in *Engineering News* of April 4, 1912, wherein is published a report of the American Society for Testing Materials' meeting, the following sentence: "The report of the water-proofing committee brought about some excited discussions, during which several persons affirmed their belief in the imperishability of concrete and protested against any hint of any other possibility." However, though "it is no doubt true that many diseases can be cured by a practitioner who strenuously denies their existence and thus encourages the patient to resist and overcome them, it can hardly be expected that defective concrete walls or disintegrating piers can be strengthened by 'absent treatment,' however vigorous be the denial of the injury or however prominent the denier." It is much better to look facts in the face and attempt to find a remedy.

Sea-water, one of the agents which brings about the disintegration of concrete, attracted the attention of users of cement

* Communicated by Professor Creighton.

soon after it was first employed in marine construction. Although a great deal of non-reinforced concrete has withstood the action of the sea up to the present, and will probably continue to do so, still some of it has failed. Although the cause of this disintegration is not definitely known, Le Chatelier and others point out [1] that it can probably be ascribed to a reaction between the magnesium sulphate of the sea-water and the lime of the cement (formed during setting) and the alumina of the aluminates of the cement, the result being the formation of magnesium hydrate and calcium sulpho-aluminate, which crystallizes with a large number of molecules of water. Notwithstanding that the other components of sea-water have usually been considered as having little effect on concrete, attention has recently been called to the fact that both sodium chloride and magnesium chloride rapidly react with the silicates in concrete.[2]

In the laboratory it is possible to destroy, almost completely, small cylinders or other forms of concrete or cement mortar by the action of solutions of various salts. The "Action of the salts in alkali water and sea-water on cement" has been the subject of a lengthy investigation by Bates, Phillips and Wig, of the U. S. Bureau of Standards, and their results have been published [3] under the foregoing title. This investigation was undertaken in consequence of disintegration of concrete, through the action of water containing magnesium and sodium sulphates, occurring in several irrigation projects in some of the Western states; and for the purpose of determining the action of various single and mixed salt solutions on concrete and cement. The salt solutions were allowed to percolate through hollow cement cylinders closed at one end, and it was found that any cement mortar may be destroyed if a sufficient amount of salt accumulates and crystallizes out. It was also found that, in general, chloride solutions were more active than sulphate solutions in removing lime from concrete, but that mixed chloride and sulphate solutions were more active than solutions of single salts.

[1] Le Chatelier, *Tonindustrie Zeitung*, 33, 931; Chandlot, "Ciments et Chaux Hydrauliques," p. 306; Michaelis, *Bul. de la Soc. D'Encourag. de l'Ind.*, June, 1897.

[2] Chandlot, *loc cit.*; Michaelis, *Bul. de la Soc. D'Encourag. de l'Ind.*, 682, 1890; D'Rohan, *Eng. Record*, July 20, 1910.

[3] Bur. of Standards, Techn. Paper 12, JOUR. FRANKLIN INST., 175, 65.

According to a recent report[4] by J. L. Harrison, District Engineer, Iloilo, the cracking of reinforced concrete structures is markedly prevalent in the Philippine Islands. A study of this trouble has shown that not a single structure showing rusted steel has been free from salt, the percentage of which varies considerably. In view of this, engineers in the Philippines have been advised that not only is the use of salt water dangerous in concrete structures, but that beach sand and beach gravel should be employed only after having been thoroughly washed with fresh water.

The foregoing, and many other similar pieces of evidence, indicate that salt and brine exert a deteriorating action on concrete.

In this paper the writer wishes to give a brief account of observations on the deterioration of reinforced concrete by salt and brine, which were made by him, a few years ago, while examining a large number of reinforced concrete structures in different parts of the country.

In order that the deteriorating action of salt water on iron may be better understood, the probable reactions which occur when this metal comes in contact with a salt solution will be briefly discussed.

When a piece of iron is placed in distilled water, it becomes negatively charged, since its electrolytic solution pressure (which is equal to 1.2×10^4 atmospheres) causes atoms of the metal to pass into solution in the form of positively charged ions, leaving an equivalent number of negative charges behind on the bar of metal. In spite of the large electrolytic solution pressure of iron, only a vanishingly small quantity of it passes into solution in the form of ions, and, consequently, the bar of metal receives but a very small negative charge. This is due to the fact that when a ferrous-ion with its large positive charge ($2 \times 96{,}500$ coulombs for every gramme-ion of the metal) leaves the bar of neutral metal the latter acquires a correspondingly large negative charge; it therefore becomes more difficult for a second ferrous-ion to go into solution, owing to the attraction between the unlike charges; and it is still more difficult for a third ion to leave the metal, and so on. Very soon, therefore, the negative charges upon the bar of metal become sufficient to prevent further fer-

[4] *Bulletin* of the Bureau of Public Works, October, 1916.

rous-ions from going into solution, and equilibrium occurs; and, unless these negative charges are removed from the metal, no more iron can pass into solution. Suppose, now, that common salt be added to the water containing the bar of iron. On dissolving, this electrolyte largely dissociates into its ions, and it may be assumed that hydrolysis takes place, although to a most limited extent, in accordance with the equation:

$$NaCl + H_2O \rightleftharpoons NaOH + HCl.$$

The concentration of these new substances being extremely small, they dissociate practically completely and give rise to negatively charged hydroxyl ions and positively charged hydrogen ions:

$$NaOH \rightleftharpoons Na^+ + (OH)^-,$$

$$HCl \rightleftharpoons H^+ + Cl^-.$$

The hydroxyl ions then unite with the ferrous-ions, that have passed into solution from the bar of metal, to form undissociated ferrous hydroxide:

$$Fe^{++} + 2(OH)^- \rightleftharpoons Fe(OH)_2,$$

which gradually precipitates as an hydrated oxide. The presence of dissolved oxygen in the solution would, of course, gradually convert the oxide and ferrous hydroxide into the corresponding ferric compounds.

The negative charges upon the bar of iron, which were in equilibrium with the ferrous-ions before the addition of the sodium chloride, now attract the positively charged hydrogen ions, the electrolytic solution pressure of hydrogen being much less (9.9×10^{-4} atmospheres) than that of iron and very much less than that of sodium ($> 10^{43}$ atmospheres). In consequence of this attraction, hydrogen ions move towards the negatively charged iron bar, touch it and become neutral, gaseous hydrogen atoms. The negative charges on the bar being thus diminished, more iron enters the solution in the form of ferrous-ions, and the foregoing process occurs again, and so on. In this way the bar of iron gradually disappears and iron oxide and hydrated oxide accumulate.

The nascent hydrogen which is produced on the bar may be absorbed by the iron; it may be oxidized by the oxygen dissolved in the solution, or it may be liberated as a gas. In order to determine whether gaseous hydrogen is ever liberated under the foregoing conditions, the writer immersed a number of pieces of iron in dilute aqueous solutions of sodium chloride contained in glass tubes with a capillary top, and connected at the bottom with a small glass tube bent upwards at right angles. Before being introduced into the glass tubes, the salt solution was boiled to remove the air, and afterwards, before sealing off the tip of the capillary, a high vacuum was applied to the solution for some time. It was found that in all the tubes a grayish-green deposit slowly accumulated near the bottom, and at the end of several months a small quantity (0.1 to 0.2 c.c.) of gas had formed in three of the tubes. This gas proved to be mostly hydrogen.

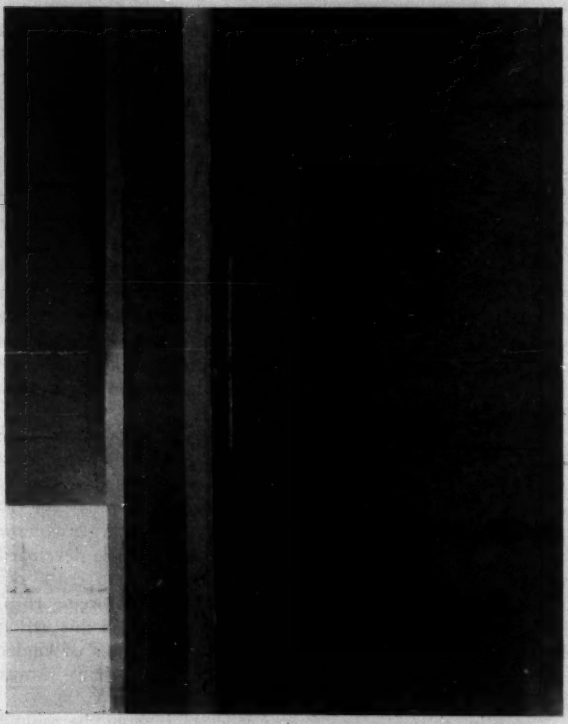
In addition to the corrosion of iron through the action of brine by the processes just outlined, auto-electrolysis may occur on account of the presence of segregated impurities which are responsible for the differences of potential established in certain areas. These potential differences bring about a galvanic action which causes the iron to go into solution at certain points with the formation of rust.

From what has been said, it is clear that reinforced concrete which comes in contact with brine or sea-water, unless rendered absolutely impervious, will commence to deteriorate as soon as the brine comes in contact with the reinforcing rods; for, as both iron oxide and the hydrated oxide occupy a larger volume than the corresponding amount of iron, there will be developed an enormous expansive force which is sufficient to crack the strongest concrete and force it away from the reinforcing rods. The more porous the concrete, the more rapidly will this action take place. Indeed, the writer is familiar with cases of cinder concrete structures, in contact with brine, which have shown signs of advanced deterioration at the end of a year.

Regarding the water-proofing of concrete, it should be pointed out that an impervious concrete is probably never obtained outside the laboratory. The average concrete is practically never water-proof. Although there are many substances on the market for rendering concrete water-proof, the majority of them

is far from satisfactory. A number of such instances has been investigated by Brown,[5] who points out that all waterproofing materials will sooner or later hydrolyze, crack, or disintegrate.

FIG. 1.



Since most concrete is more or less porous to moisture, and since iron undergoes gradual decomposition, in the presence of salt water, with consequent expansion in volume, it is to be

[5] *The Electrician*, 69, 915 (1912).

expected that reinforced concrete which comes in contact with brine or salt and moisture will ultimately disintegrate. It is not surprising, therefore, to find throughout the country reinforced concrete piers, sea walls, and buildings in the neighborhood of the ocean in various stages of deterioration. The cracks which occur in such concrete usually run parallel to the reinforcing rods. These cracks are very narrow at first, but as the decomposition of the iron progresses they become iron-stained, gradually increase in width, and, finally, the concrete is forced so far from the reinforcing rods by the pressure of the accumulating iron oxide that large pieces of it break off.

FIG. 2.

In many parts of the country to-day there are reinforced concrete structures housing industries that use large quantities of salt and brine, which are constantly spilled on the floors. In order to ascertain whether the concrete of such buildings has undergone any deterioration, the writer a few years ago examined a large number of them in different cities throughout the country. In practically all the buildings inspected, reinforced concrete floors which came in contact with brine had iron-stained cracks on the under side. Usually these cracks were very narrow, but they indicated, nevertheless, deterioration of the reinforcements, and would continue to grow as the disintegration of the iron progressed. Fig. 1, which is a photograph of the ceiling of a large reinforced concrete building in Detroit, the floors of which are

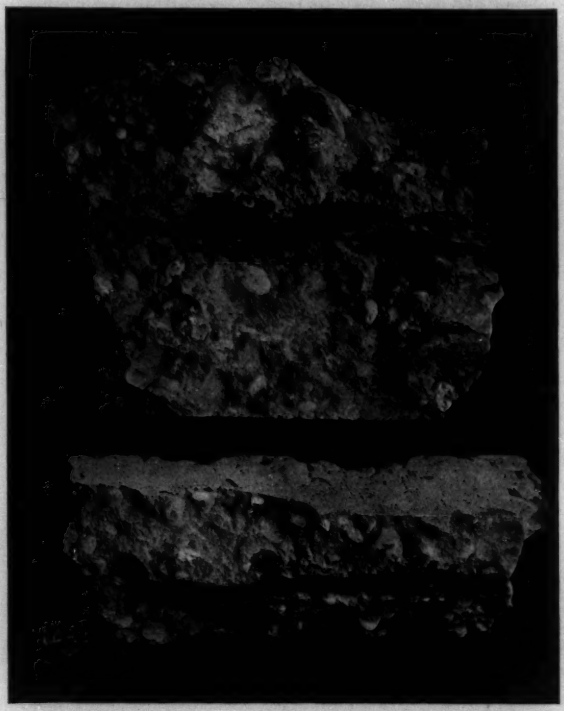
continually wet with brine, is a typical example of one of these iron-stained cracks in the early stages, and Fig. 2 shows a cracked horizontal beam supporting the floor of a reinforced concrete building in Chicago. In many instances the cracks were found to vary from ⅛ to ¼ inch in width, and in some cases deterioration had progressed so far that large pieces of concrete had fallen, or were about to fall, leaving the badly corroded reinforcements

FIG. 3.

exposed, as illustrated by Fig. 3 (photograph taken in Buffalo). An examination of a number of pieces of this fallen concrete showed that in every case a quantity of iron oxide adhered to the concrete where it had come in contact with the reinforcing rods (Fig. 4), and that it was sometimes as thick as ⅛ inch. Where the concrete had broken away from the reinforcements, the latter were usually so badly corroded that it was possible to remove thick layers of oxide with the fingers. In a few cases the deterioration had progressed to such an extent that the rein-

forcements had been completely converted into oxide. Fig. 5 shows pieces of iron oxide, $\frac{1}{8}$ to $\frac{3}{16}$ inch thick, which were pulled away from corroded reinforcing rods or beams with the fingers.

FIG. 4.

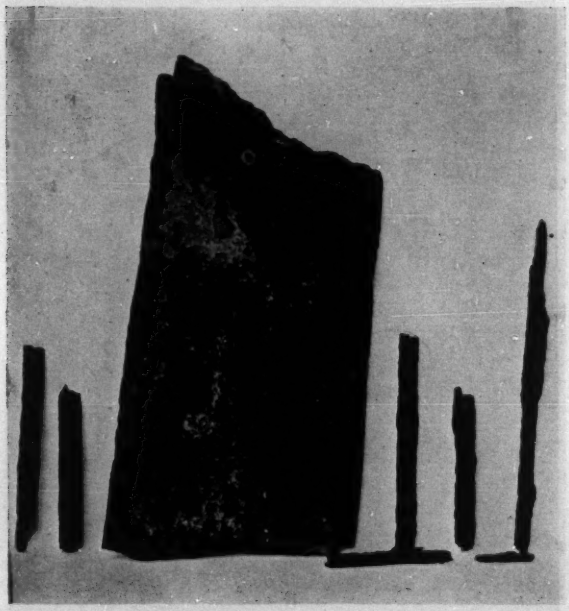


A few details regarding particular cases of deterioration met with in some of the reinforced concrete structures examined may be of interest.

The ceiling of a machine shop of a large reinforced concrete plant in East St. Louis was found to be very badly damaged.

This building, at the time of inspection, was about ten years old. The upper side of the ceiling was continually wet with brine, which constantly leaked through to the under side and wetted it in a number of places. On this ceiling large, brown iron-stains were numerous and in at least twenty places pieces of concrete had fallen, leaving badly corroded, net-iron reinforce-

FIG. 5.



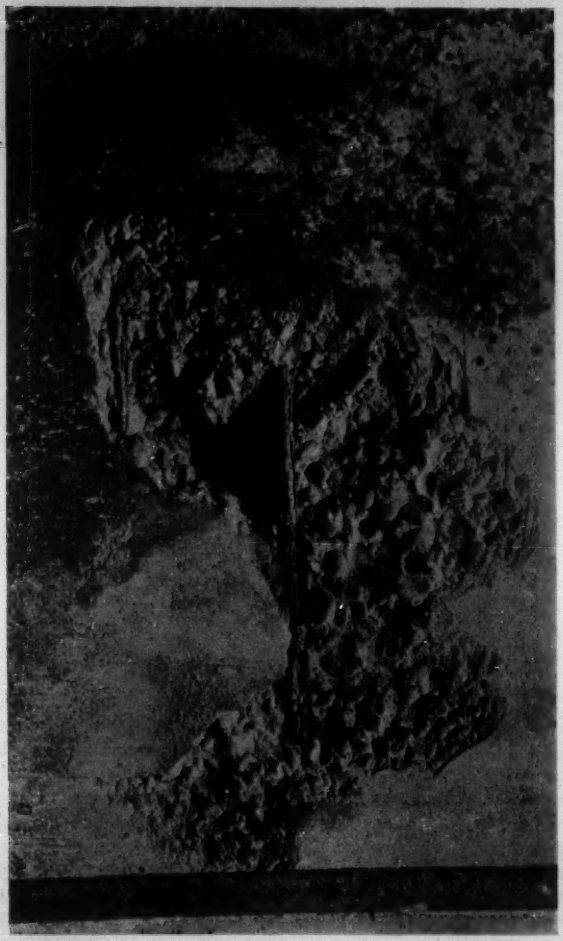
ments exposed. In one place a piece of concrete twelve feet long and varying from two to eighteen inches in width had broken away. The reinforcements of this ceiling were imbedded at a depth of about ¾ inch from the surface. Photographs of this ceiling are shown in Figs. 6, 7 and 8. Examples similar to these have been observed by the writer in Chicago, Kansas City, Detroit, and Buffalo.

At a plant in Kansas City there was found a very interesting cracked reinforced concrete pillar which supported a reinforced concrete platform at the top of an outside staircase. Large quantities of salt were used in the plant, and the platform was often wet with brine. The cracks on the pillar ran parallel to the longitudinal reinforcing rods. In some places the concrete had fallen away from the rods, which were badly corroded, and in others portions of the concrete were easily pulled away. A photograph of this pillar is shown in Fig. 9.

FIG. 6.

At another plant in this city there was a long outside platform, from which cars were loaded, covered by a reinforced concrete roof. At one end of this roof there was a pile of rock salt, which was partially protected from the weather by a wooden roof. Rock salt had been stored in this place for years. For a number of yards beyond where the salt was stored it had been spilled continually on the concrete roof, and, owing to rains, perhaps a quarter of the roof was frequently wet with dilute brine. On the under side of the roof, directly below this place, there were many brown iron-stains, wet patches, salt deposits, and in one place

FIG. 7.



the concrete had fallen, leaving the net-iron reinforcings exposed. These had deteriorated to such an extent that the outer portions crumbled on touching and some of the rods were easily pulled away. The area from which the concrete had fallen was at least one square foot. The individual rods of the exposed net-rein-

FIG. 8.

forcing, originally about $\frac{1}{8}$ inch in diameter, had increased to about $\frac{1}{4}$ inch in diameter, owing to the conversion of the iron into oxide. Some of these rods had disintegrated to such a degree that the sound iron core was less than $\frac{1}{25}$ inch in diameter. Near where the concrete had fallen, it was evident that

the expanding reinforcings were gradually forcing the concrete downwards. At the far end of the ceiling, where salt had not been spilled above, there was no evidence of deterioration and the concrete was in an excellent condition.

At a third plant in Kansas City, a five-year-old, reinforced concrete, basement ceiling was found to be in a very bad condi-

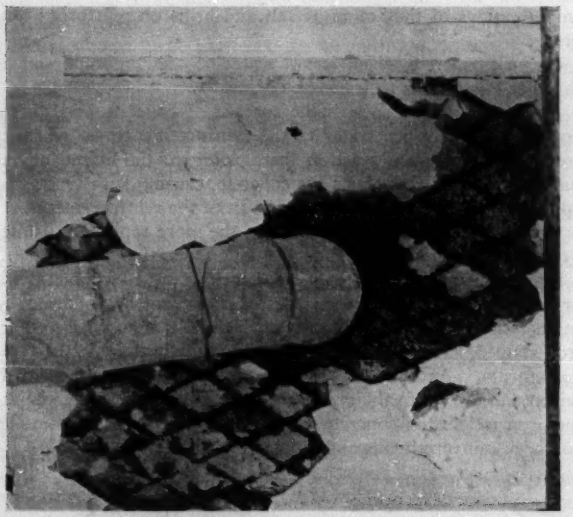
FIG. 9.

tion. This ceiling was reinforced with ¾-inch twisted iron rods. The floor above was more or less wet all the time, and, in places, salt came in contact with the water, forming brine. There were many cracks on this ceiling, some of which were sufficiently wide to insert a lead-pencil. One such crack was twenty to thirty feet in length. In several places large pieces of concrete had fallen, leaving corroded reinforcements exposed.

In one place a large piece of concrete which was almost dropping and which weighed about twenty-five pounds was easily pulled away from the reinforcements. The under side of this, as is usually the case, had a large portion of the corroded reinforcements adhering to it.

The writer examined a building in Kansas City which contained a large quantity of reinforced cinder concrete that came into contact with considerable amounts of brine. This concrete,

FIG. 10.



which was thirty years old, was in a very damaged condition, and in many places very large pieces had fallen.

In one of the Chicago plants examined, a whole floor had collapsed about a year previously, owing to the weakening of the reinforcements by disintegration.

Similar cases to the foregoing have been found by the writer in a number of cities in different parts of the country. An excellent example of deterioration of reinforced concrete found in Buffalo is shown in Fig. 10.

When concrete construction is carried out in winter, it is sometimes the practice to add salt to the concrete to prevent freezing, often as much as twenty per cent. being added. The writer has examined a number of reinforced concrete structures where salt had been mixed with the concrete during construction. As is to be expected, where the concrete comes in contact with water or moisture, there are manifold evidences of deterioration; but, on the other hand, where the concrete has been kept dry no damage has been observed.

The following conclusions are drawn by the writer from his investigations of the action of salt and brine on reinforced concrete:

1. All concrete which is not water-proofed in some way is more or less porous to water and brine.

2. Brine readily softens the surface of concrete and, therefore, more easily penetrates to the reinforcements, on which it exerts a disintegrating action that, owing to the attendant expansion, gradually weakens the concrete, causing it to crack and split, and in some cases to fall away from the reinforcements.

3. The more porous the concrete, the more rapid the disintegration of the reinforcements through the action of brine.

4. Reinforced concrete floors which come in contact with brine will gradually develop leaks. These will be followed by incrustations of discolored salt on the under side, where, later, iron-stained, hair cracks will develop running parallel to the reinforcements. As the deterioration progresses, the cracks will widen and, owing to the great expansive force of the accumulating iron oxide, the concrete will be gradually pushed from the corroded reinforcements and ultimately fall.

DEPARTMENT OF CHEMISTRY,
Swarthmore College,
July 27, 1917.

THE PHYSICAL CHARACTERISTICS OF THE ELEMENTARY GRAINS OF A PHOTOGRAPHIC PLATE.*

BY

MILLARD B. HODGSON.

WHEN we speak of "grain" in a photographic plate, we generally use the term in a rather loose sense. We employ it to denote, in a general way, both the characteristics of the individual granular deposits of silver and the arrangement or agglomeration of these constituent particles, as an entirety, with sometimes emphasis on one phase of the subject and sometimes on another.

It is the purpose of the present paper to sharply differentiate between these two phases by outlining a few fundamental conceptions of plate grain; also to present some of the more interesting data obtained in the study of the elementary particles of a silver halide emulsion.

There are present, in nearly all developed and dried photographic plates, deposits of silver of varying size and shape. On close examination it is found that these deposits are made up of small elementary units, which in a high-speed plate negative vary in size, from the ultra-microscopic to five or six microns in greatest dimension, the average variation being from 0.2 μ to 4 or 5 μ, and the mean size about 2.5 μ.

Fig. 1 shows a photomicrograph of a section of a high-speed photographic negative, illustrating these elementary units. These elements are grains in the strict sense of the term, for, as will be shown later, they are inherently conditioned in position and size by the position and size of the original silver halide grains. That is, they are to a certain extent isolated from each other by intervening walls of gelatine.

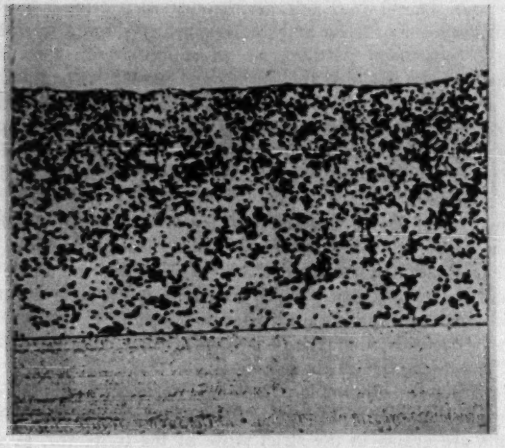
In viewing a dried down negative, however, by transmitted light, under moderate magnification, or none at all, we see not these isolated grains, but, in effect, agglomerations of grains by the projection of light through interstices between many grains in numerous "grain planes" throughout the emulsion layer. Therefore since the average layer is about six grains deep, and

* Communicated by Dr. Mees. Communication No. 56 from the Research Laboratory of the Eastman Kodak Company.

since the grains themselves are distributed on a probability basis in each layer, we obtain more or less regular large patches and chains of grains as a result, the pattern and regularity depending on the particular type of emulsion used.

It is this granularity which makes up what is commonly meant in speaking of grain. It is the grain met with in projection work, in enlarging and in portraiture.

FIG. 1.



Section showing individual silver grains. Magnification, 350 diameters.

This overlapping and agglomerating of grains can be seen nicely by observing a horizontal plane view of a photographic film through the entire emulsion, in comparison with a thin vertical section through the same film (Fig. 2).

It is not the purpose of this paper to discuss the matter of plate granularity, meaning agglomeration of individual grains, which phase of the subject is now the subject of investigation in this laboratory.

As has been stated, the physical characteristics of the developed elemental grains depend largely upon the characteristics of the elemental silver halide grains.

Silver bromide occurs, in the average emulsion, in the form of more or less regular semi-transparent crystals belonging to the isometric system, the most regularly recurring figure being the tetrahedron. The larger grains are evidently builds or aggregates of hemihedral tetrahedra or other imperfectly developed forms. In addition there are present numerous fragmentary and truncated particles.

The physical characteristics of these grains seem to be con-

FIG. 2.—A.

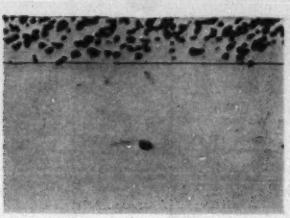
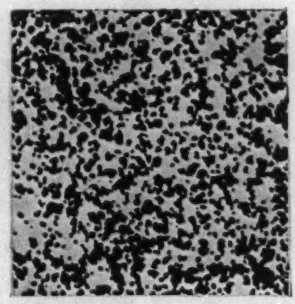


FIG. 2.—B.



"A," vertical section, showing grain-deposit. "B," horizontal plan of grain deposit. Magnification, 375 diameters.

trolled by the method by which the silver bromide is precipitated, on the temperature of precipitation, amount of gelatine present, concentration and presence of additional salts.

A fairly accurate idea of the size, etc., of these crystals will be gained from the values given in Table I, which gives the physical characteristics of four typical emulsions.

TABLE I.

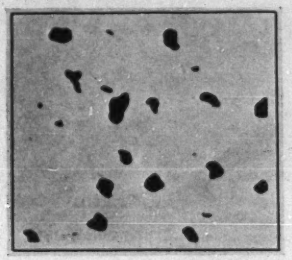
Plate	Average grain size *	Range in grain size †	Shapes
Cine Positive Film	1.0μ	0.2 – 2.0μ	Regular, uniform
Seed 23 Plate	2.0μ	.2 – 3.5	Regular, uniform
Seed Graflex Plate	3.2μ	.2 – 6.0	Irregular, wide variety
Special Experimental Emulsion	4.0μ	.2 – 8.5	Very regular, variety

* Greatest dimension.
† Resolved.

The fragmentary grains are very numerous in nearly all emulsions. The special experimental emulsion referred to in the above table proved to be very adaptable for the study of individual grain characteristics, its great regularity in shape and freedom from fragments reducing confusion in microscopic examination to a minimum. However, it does not differ greatly, except in this matter of regularity, from the performance of other emulsions, hence the author feels justified in basing certain conclusions on the performance of this emulsion.

The question has often arisen: Are these unexposed grains crystals of pure silver or are they composed of a gelatino-silver

FIG. 3.



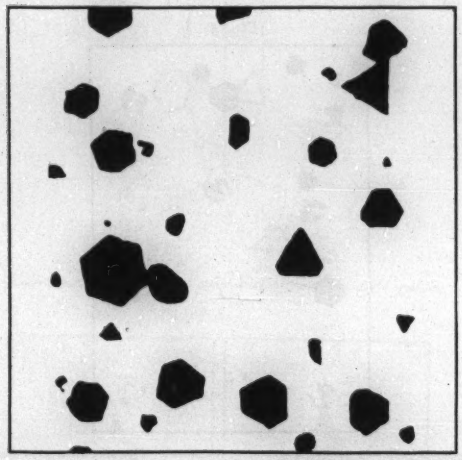
Developed grains. Seed graflex. Magnification, 1350 diameters.

complex? From the results of this investigation it seems logical to assume that the inner mass of the grain is pure silver salt, for when water strikes the unexposed crystals no swelling is at all observable, even under the highest power magnification. However, in the majority of cases, when development is complete, the silver deposit is vastly different in form from that of the parent crystal. During development the growing silver mass becomes twisted and distorted. This suggests strong external forces at work, probably due either to an adsorbed layer of gelatine or to almost perfect adhesion to the surrounding gelatine. In the silver bromide crystal, even when water is present in the system, this strain is insufficient to break down the cohesion of the particles of the crystal and distort it, but when the spongy deposit of silver begins

to form, in soot-like particles, the enveloping " bag " of gelatine more or less distorts it.

In the average high-speed plate this distortion is great, causing the developed grains to resemble black popcorn or irregular chunks of coal. In the plate " Special No. 1 " this distortion is at a minimum, the developed deposits being almost entirely within the confines of the original crystal. Figs. 3 and 4 illustrate these

FIG. 4.



Developed grains. "Spec. No. 1." Magnification, 1350 diameters.

typical extreme cases. From Fig. 4 we can also gain information as to the geometrical form of the parent crystals.

As has been previously stated, these developed grains are masses of fine, sooty black silver, held together by the surrounding gelatine. They may be separated by swelling the gelatine or by applying other mechanical force.

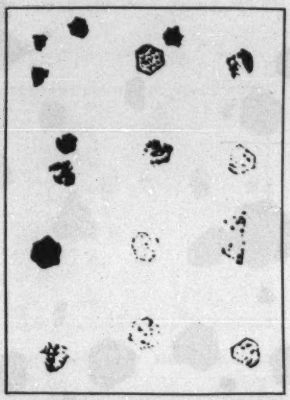
The progress of the development of individual grains has been studied in detail by the following method:

Regularly coated plates were flashed to light, developed slightly, and washed thoroughly to arrest and remove developer.

Some of the emulsion was then removed and examined under high-power magnification. Fig. 5 shows a number of such grains at various stages of development. In most cases development starts at considerably more than one particular point, even in the case of small fragments, and continues (providing time is allowed) until the entire crystal is reduced.

In no case of normal procedure has a curious phenomenon described by Scheffer[1] been observed. Scheffer described and illustrated the development of silver bromide grains under high-

FIG. 5.



Silver bromide grains in various stages of development. Magnification, 1350 diameters.

power magnification. He showed that in his specimens the grains shot out, or grew, feelers or tentacles during development. These tentacles were subsequently capable of affecting other silver bromide grains, inasmuch as contact seemed to cause developability.

In only one particular series of enormous overexposures, developed under the arc illumination of the microscope, have any such phenomena been observed by the author. The emulsion in the case in question was coated in a very thin film on the micro-

[1] W. Scheffer, "Microscopical Study of Silver Grains," *British Journal of Photography*, 1907, No. 2441, vol. 54.

slide. The primary cause of the shooting out of feelers was here considered to be due to channels or fissures opening up in the gelatine when the developer struck it. In the case of normal thickness of coating (10 to 30 microns) the elastic action is gradual enough in the case of drying after coating and in subse-

FIG. 6.

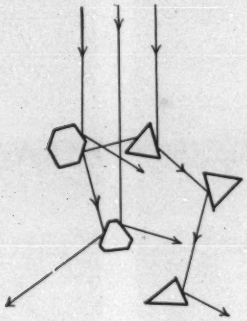
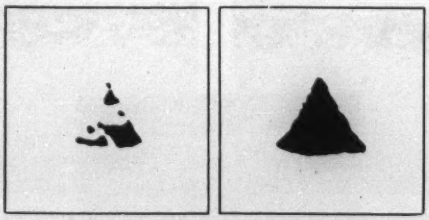


Diagram representing scatter of incident light by silver bromide crystals.

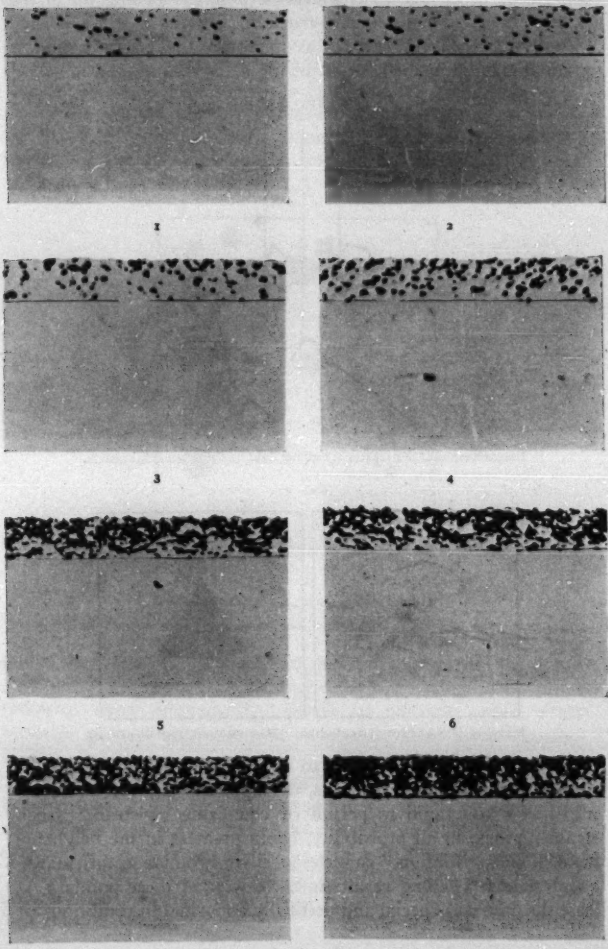
FIG. 7.



Stages of development of single grain. Magnification, 5000 diameters.

quent swellings to allow time to adjust internal strain. In the case of extremely thin coatings, drying, after the original coating, is far too rapid to permit of equalizing of strain. Such strain regions, in all probability, being greatest in the neighborhood of such " foreign " particles as silver bromide grains, subsequent sudden swelling results in a cleavage at these points. At least the case was special and decidedly abnormal in conditions of

FIG. 8.

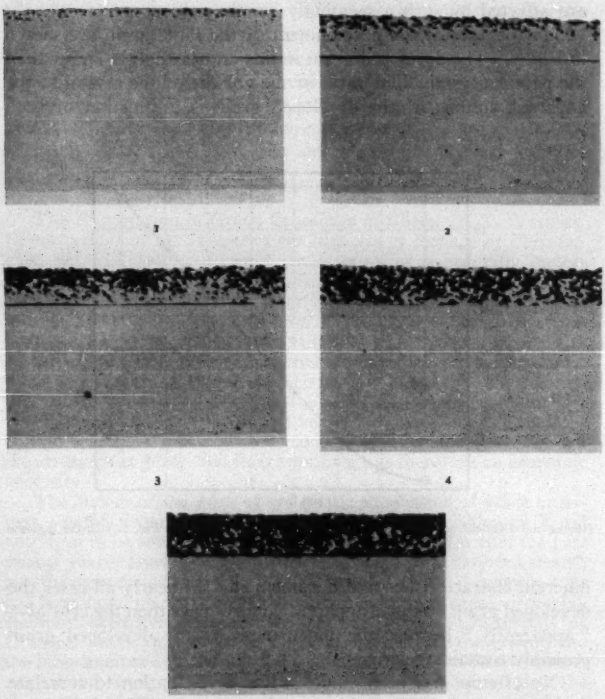


Series of vertical sections (dry), showing growth of image with exposure. Magnification, 375 diameters.

exposure, physical characteristics of the emulsion layer, and development.

In all cases of normal conditions development seems to be a

FIG. 9.



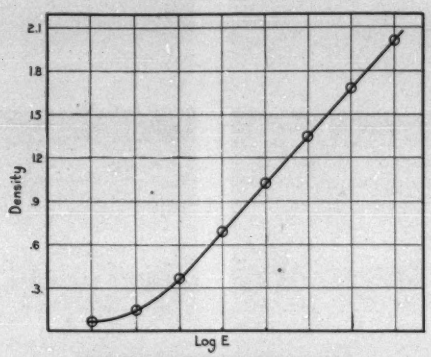
Series showing growth of image with development. Magnification, 375 diameters.

more or less steady transition from silver salt to reduced silver, with the gelatine functioning to cause some distortion of the shape of the individual deposits.

Since the development of a grain starts at a number of points at once, it follows that there must be formed, even in a short exposure, numerous nuclei. This is not to be wondered at when we consider the scatter of light by the emulsion layer (Fig. 6). Probably thousands of molecules or crystal units of each grain are affected by such a seemingly simple exposure.

Two stages of the development of the same grain are shown in Fig. 7. The developed grain in this case is slightly larger than the parent crystal. The ratio of the volume of the crystal to the apparent volume of the developed grain is a function of both

FIG. 10.



Hurter and Driffield curve of strip of which sections are shown in Fig. 8. Circles indicate densities of sectioned parts.

inherent characteristics and development. In nearly all cases the developed grain occupied apparently more space than the crystal—"apparently," because the inner mass of the developed grain probably contains gelatine.

No attempt has been made in this investigation to correlate the performance of individual grains with the behavior of the sensitive film as a whole.

The effects of exposure and development and developer on the entire mass, and a study of the resulting "graininess," has not been touched on. However, in the sectioning of dry film to study grain size some interesting photomicrographs were obtained which

are shown in Figs. 8 and 9. Fig. 8 shows a section of each step of a Hurter and Driffield test strip whose D-log E curve is given in Fig. 10. The developer in this case was pyro-soda. The density gradient in each case is somewhat surprisingly shallow.

Fig. 9 shows the developing stages of equal exposures after varying times of development. Many of the fine grains at the lower edge of the image are no doubt parts of large crystals whose development was arrested.

In conclusion I wish to express my indebtedness to Mr. L. A. Jones and Dr. S. E. Sheppard for numerous helpful suggestions given during the course of this investigation.

ROCHESTER, N. Y., September, 1917.

The Elimination of Grade Crossings in Cities. S. T. WAGNER. (*Transactions of the Wagner Free Institute of Science of Philadelphia*, vol. viii, July, 1917.)—A grade crossing is generally understood to mean the crossing of a railroad by a highway when both are at the same level. The same term is applied to the crossing of one railroad by another at the same level. The existence of grade crossings is a necessary evil. When railroads were first constructed in places where the grade crossing is now in existence, there was no other way in which many of these could have been built. At the time the railroads were built, neither the railroads nor the communities which have grown into towns and finally into cities would have been able to bear the expense of construction which would have avoided the crossings at grade, and their existence was therefore an economic necessity.

The history of the work of systematic elimination of grade crossings possibly extends back to about the year 1880, although it did not begin to be considered an important subject until within the past twenty years. During the past fifteen years progress has been steady, and the movement toward the elimination of the most dangerous ones has been rapid on the part of the cities and the railroads. Probably the most extensive work of that kind has been done in the city of Chicago, where, on account of the level character of the ground and the large number of railroads, the conditions are worse than in almost any of the large cities of the United States. It is stated that the elimination of 780 grade crossings had been arranged for in Chicago up to 1911. Philadelphia is credited with the next largest number, namely, 120, and Buffalo third, with 94 to its credit.

In general there are six methods by which a grade crossing can be abolished: (1) Raising the street over the railroad; (2) lowering the street under the railroad; (3) lowering the street and raising the railroad; (4) raising the street and lowering the railroad; (5) rais-

ing the railroad over the street; (6) lowering the railroad under the street. In all these cases it is evident that either the street or the railroad must increase its rate of grade, and this single point is generally the most difficult one to deal with in any particular case: the increase in the rate of a grade of a railroad is always accompanied by loss of revenue. On a street it is difficult to calculate actual money loss by increasing the grade. Unfortunately the elimination of such crossings is not profitable to either the city or the railroad from a financial standpoint. Neither can expect to receive any financial return for the large amounts which must be expended.

The Gowlland Multifocal Spectacle Lens. H. O. GOWLLAND. (*Gowlland Optical Company, Limited,* Montreal, Canada.)—Bifocal spectacle lenses for near and distant vision have been known and used since the time of Franklin, and within recent years, particularly since the introduction of "invisible" bifocals, their use has become widespread. Although these lenses obviate the need of two pairs of glasses, the wearer often experiences the discomfort of the "blind zone," or an area within which the distance part of the lens is of too long focus and the near part of too short focus for satisfactory vision. If this blind zone is to be eliminated, a compromise must be made in the powers of the two lenses and the user must be content with less than the maximum possible clearness of vision. A lens of continuously varying curvature within the required limits would evidently provide the necessary conditions for distinct vision at all distances. Such a lens, not having a spherical surface, entails a departure from the usual methods employed in the production of spectacle lenses.

The Multifocal lens embodies this continuous variation of focal length, the difficulties incident to a departure from a truly spherical surface having been successfully overcome. In the manufacture of these lenses the usual system of working has been reversed. The master tool first grinds the curve to a certain degree of fineness, and after that the lens surface itself controls the smoothing and polishing, the surface retaining its ground curve. The finished lens is a clear piece of glass with constantly changing curvature, whose rate of change is governed by the extreme values of the curvature.

While the line of contact between the distance and near parts in the so-called invisible bifocals is quite discernible, the Multifocal lens is free from this characteristic. It is undoubtedly true that the field of view at any given focal value is theoretically limited to points equally distant from the vertex of the curve, but practically, with the relatively small curvatures of spectacle lenses, vision is clear over a considerable zone and an adequate field of view is obtained. The user is thus provided with a lens that responds to the varying requirements of close work and is free from the disconcerting visual jar of an accidental use of the wrong power of the bifocal lens when moving about in an uncertain light.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE EFFECT OF VARIOUS PHYSICAL STIMULI ON THE PUPILLARY AREA AND RETINAL SENSIBILITY.[1]

By Prentice Reeves.

[ABSTRACT.]

As there is such a close analogy between the kodak and the eye, an extensive series of investigations is being carried on in physiological optics in this laboratory and this paper gives a brief summary of some of the results obtained up to this time. By making a detailed study of the functions of the eye it is hoped that some information may be discovered relating to some of the new uncertain points in photography.

The eye and the photographic plate are the most widely used instruments for studying light problems, and in practically all cases the final judgments are rendered by the eye. The eye operates through a range of ten billion to one, and maintains a remarkable efficiency throughout a greater part of this extensive range. By knowing the efficiency at which the eye operates we are able to determine the accuracy to which photographic results may be determined.

In this research one of the problems studied was the least amount of physical radiation which will give rise to a perception. This depends on several factors, the greatest of which is the adaptation of the eye. When the eye is fully adapted to absolute darkness its sensibility is the greatest, and the threshold obtained under this condition gives the absolute photochemical reactivity of the retina. When viewing a 1-mm. spot at a distance of 3 metres the minimum radiation visually perceptible was found to be 17×10^{-10} ergs per second. When the test-spot was increased to a 3-cm. square and the observing distance was 35 cm., a dark-adapted eye could just perceive a brightness of

* Communicated by the Director.

[1] Communication No. 52 from the Research Laboratory of the Eastman Kodak Company, published in *Journal of Ophthalmology, Otology and Laryngology*, September, 1917, and *British Journal of Photography*, 1917, p. 415.

44×10^{-7} millilamberts, while if the eye was adapted to a brightness of the average bright sunny day, the least it could see was about 2 ml. When the size of the test-spot was increased in steps from a 2-mm. square to a 12-cm. square, the results show that the sensibility varies directly as the visual angle up to a value equal to the angle of the fovea and then rises gradually as the peripheral regions are stimulated. By placing an accurately calibrated shutter before the test-spot a series of determinations was made to determine the intensity to which the stimulus should be illuminated to be perceived when exposed for a given period of time.

The distinguishing of detail under all conditions is the fundamental requirement of efficient vision, so the next step was to determine the contrast sensibility of the retina. It was found to increase with an increase in field brightness through the lower intensities, remain constant for the brightness of ordinary vision, and drop off for higher intensities. Throughout ordinary vision the eye is able to detect a difference of 1¾ per cent. in brightness between two adjacent fields. In the determination of glare sensibility it was found that the average eye, when adapted to darkness, could just tolerate a brightness of 25 ml., while if it were adapted to a bright sunny day, the eye could stand a brightness of 16,000 ml. These values give us an idea of what we can see, how well we can see, and what we can comfortably endure.

When the eye is subjected to a change in the brightness of the environment it automatically adjusts itself to the new condition. If the amount of the change is small, the eye adjusts itself practically instantaneously, but if the change is great, an appreciable amount of time elapses. When changing from a given brightness to darkness the eye adapts quite rapidly for the first few minutes and continues to adapt slowly for several hours, although for practical purposes an equilibrium is reached after an hour. When colored light is used we find adaptation is least and most slowly for red, then come yellow, white, green, and blue. When the change is from a low to a higher intensity the change is much more rapid, and a person "gets his eyes" quicker when turning on a light than when turning out a light.

Accompanying the change in sensibility just described is a change in the pupillary diameter, and, while the former varies over a million to one, the latter varies only about 16 to 1. A

series of photographs was taken of several subjects over a range of brightnesses from utter darkness to the reflection of direct sunlight from a white paper screen. The average diameter for dark adaptation was 8 mm., the largest diameter for any pupil was 8.6 mm., and the average minimum diameter was 2 mm. The effect of exposing one or both eyes to a given brightness is shown in the following table. The photographs were taken of the right eye in both cases, and the difference between the results in the second and third columns shows the effect of closing the left eye.

TABLE I.

Brightness in millilamberts	Diameter in millimetres	
	Both eyes open	One eye closed
0.0	7.4	7.5
0.00015	7.15	7.25
0.60	5.3	6.5
6.3	4.1	5.7
126.0	2.6	3.3
2000.0	2.0	2.0

ROCHESTER, N. Y., September 29, 1917.

THE MINIMUM RADIATION VISUALLY PERCEPTIBLE.[1]

By Prentice Reeves.

[ABSTRACT.]

THE previous investigations of the least perceptible radiation have in most cases used stellar light sources and have taken various uncertain values for the area of the pupil. In the present paper the writer used a direct laboratory method, where all physical stimuli were under accurate control and there were no troublesome atmospheric conditions, as in stellar observations. Another advantage was the use of the observers' pupillary measurements obtained from instantaneous flashlight photographs.

To approximate conditions of stellar observations a stimulus one millimetre in diameter was viewed from a distance of three metres. The brightness of the "star" could be varied by the

[1] Communication No. 51 from the Research Laboratory of the Eastman Kodak Company, published in *Astrophys. Jour.*, September, 1917, p. 167.

observer and the threshold determined. The observer remained in total darkness for at least fifteen minutes to assure dark adaptation, and used a fixed head rest for constant visual fixation. The results taken under the same conditions from day to day vary through wide ranges and are explained by variations of the pupil, factors of attention and fatigue, ideo-retinal light (caused by retinal circulation), after-images, involuntary eye movements, and the general physiological condition of the observer. As these variable factors are largely beyond experimental control, the only method is to take as many observations as possible over a wide range of time and accept the general average as the threshold value. The writer's threshold value is the average of numerous observations, and results were also obtained from two other observers and averaged with the writer's values for those days.

If we let B = normal candle-power per square centimetre of source, and assuming the inverse square law and a point source, the flux through 1 square centimetre on the axis at the eye will be

$$SB/R^2 \text{ lumens}$$

and the flux through the pupil of area A will be

$$F_p = SBA/R^2 \text{ lumens.}$$

Now $B = \text{Lumen}/\pi$ and $A = \pi r^2$

so $F_p = SL\ r^2/R^2$

where F_p is the flux through the pupil, S the area of the star, L the star brightness in lamberts, r the radius of the pupil; R is the distance of the eye from the star. If the equation is then multiplied by the mechanical equivalent of light, M, we get

$$\text{Least perceptible radiation} = SLM\ r^2/R \text{ ergs per second.}$$

Using the 1-mm. star at a distance of 3 metres, the writer's values for L and r were 0.0072 millilambert and 4.65 mm., which gives a result of 17.1×10^{-10} ergs per second. The average result for three observers was $L = 0.0088$ ml., $r = 4$ mm., and least perceptible radiation = 19.5×10^{-10} ergs per second.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

THE CONSTITUTION AND FUNDAMENTAL PROPERTIES OF SOLIDS AND LIQUIDS. PART II.—LIQUIDS.[1]

By Irving Langmuir.

THIS paper extends the application of the viewpoint of Part I—Solids (*Journal of the American Chemical Society*, 38, 2221–95, November, 1916)—to a consideration of the structure of liquids.

An extended discussion of the phenomena and forces involved in the spreading of oil films upon water is followed by the following general conclusions:

"*A.* Forces of the type which Gurvich has called physical forces do not play any important part in the structure of matter. The best examples of the physical forces are gravitation and the forces between electrically charged bodies. Gravitation is much too small a force to be of influence in holding atoms and molecules together. In all ordinary matter the negative and positive electricity are so uniformly distributed throughout the mass that the effective range of these electric forces is only of atomic dimensions.

"*B. All* the interatomic and intermolecular forces involved in the structure of matter are chemical forces; that is, they are of the same nature as the forces that the chemist has been studying in the past. In general, these forces are of two kinds: those represented by primary and those represented by secondary valence."

Needed Improvement in Primary Batteries. ANON. (*Electrical World*, vol. 70, No. 15, p. 703, October 13, 1917.)—The really serious need of improvements in primary batteries has been repeatedly suggested. This need is just now sharply emphasized by the very wide use of electric flashlamps in the trenches. A flashlamp is practically indispensable as part of the equipment of all officers and of all men who have to share in the cave life of the western front. The advent of the tungsten lamp has given a very practicable source of light which does not make severe demands for current and

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* Communicated by the Director.

[1] *Journal of the American Chemical Society*, 39, 1848–1906, September, 1917.

is altogether successful for the purpose intended. But who shall say that the ideal battery for such service has yet made its appearance? The battery now almost universally used is of an old familiar type, somewhat improved in detail and really a wonderfully good article for its price, but it is essentially a battery strictly for temporary use and deteriorating on open circuit. The resources of the chemical engineer ought to be able to give us a source of electricity combining compactness, comparative freedom from polarization, and reliability. Of course, the cheaper the better, other things being equal, but it need not attempt to compete with the common type in the mere matter of first cost. Of chief importance is that it should hold up its voltage well and be free from serious deterioration when not in use. Surely the resources of invention at the present time ought to give us a battery much more suitable for hard service than the Leclanché type of cell, which has heretofore had the field practically to itself. Nothing has been able to compete with this old-timer for general use, but its limitations are such as to point the need for a successor. The thanks of the men in the trenches and no small monetary reward are likely to come to him who first produces the battery required.

Steel Reinforcing in Wooden Ships. ANON. (*Iron Trade Review*, vol. lxi, No. 13, p. 658, September 27, 1917.)—In addition to the immense steel shipbuilding program of the reorganized shipping board, over 300 seagoing wooden vessels of various types are under construction in American yards. Even these vessels, however, must pay their tribute to the iron and steel industry. It is estimated that about 60,000 tons of steel will be required for the wooden vessels now on the ways or under contract. Most of the steel will be used for fastenings, including spikes, drift bolts, through bolts, nuts, washers, clinch rings, etc.

In order to provide the necessary strength, large wooden vessels must be reinforced with steel straps. Universal plates 14 inches wide and ¾ inch thick are sometimes used. The arch rises amidships to a point 3 feet above the main deck. At both ends the straps run down to the line of the bilge. In addition, the deck beams are tied together by ¾ × 4-inch steel straps laid in four courses the full length of the ship. This strapping is rather expensive, the type used costing about $3000, including $1500 for labor and fastenings. This form of reinforcing, however, is not nearly so elaborate as that provided in the standard design of the United States Shipping Emergency Fleet Corporation. This design provides for a lattice work of steel straps, ½ × 4 inches, connected to a ¾ × 8-inch steel cord at the top. It costs about $8000 to reinforce a ship.

Cast-steel knees are extensively used by wood-ship builders on the Pacific coast. These knees are about 4 feet on a side, the metal being approximately ¾ inch thick. They are placed under the ends of deck beams, thus adding to the rigidity of the hull structure. The steel foundries on the Pacific coast have built up an attractive business manufacturing these knees.

NOTES FROM RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

SOME EXPERIMENTS ON THE EFFECTS OF CHANGES IN DIAPHRAGM THICKNESS ON THE CHARACTERISTICS OF A TELEPHONE RECEIVER.

IT was shown by Lord Rayleigh [1] that the natural frequency of a circular plate diaphragm, such as is used in a telephone receiver, is directly proportional to the thickness and inversely proportional to the area of the plate. This is on the assumption that the material of the plate remains uniform and homogeneous, and that all other conditions remain constant.

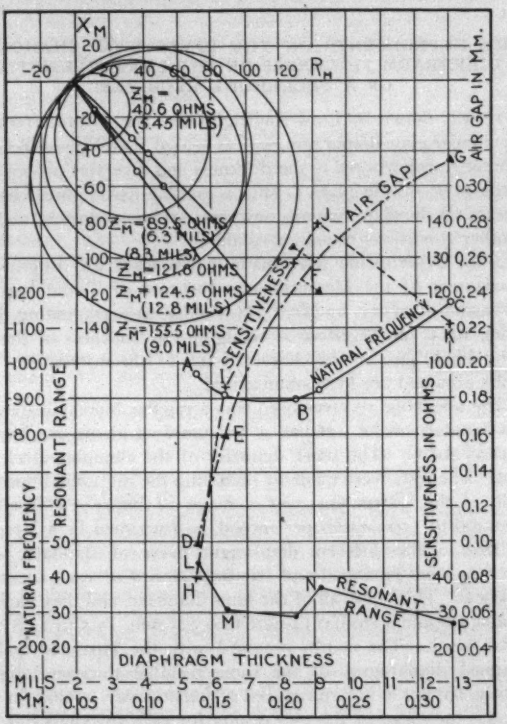
Some experiments were made in the Electrical Engineering Department of the Massachusetts Institute of Technology and Harvard University, by Mr. C. H. Calder, in a graduating thesis, during 1915, on the effect of changing the thickness of the telephone diaphragm on the characteristics of the instrument. The results obtained are here summarized.

The telephone receiver used was a regular bipolar instrument of a standard make. It had a resistance of about one hundred ohms at 20° C. The inner diameter of the clamping circle was 5 cm. The tests were made by obtaining the motional-impedance circle of the instrument over a range of impressed frequency from 400 to 1500 cycles per second, as furnished by a Vreeland oscillator. The different diaphragms were of standard ferrotype steel, one japanned and one unjapanned of each successive thickness. They were all of the same diameter, and they varied in metallic thickness from 0.14 mm. to 0.325 mm. (5.5 to 12.8 mils) in five steps. The results obtained with the japanned and unjapanned diaphragms of the same metallic thickness differed slightly, but not in any recognized systematic way, so that, in what follows, the mean of the two results for each thickness has been taken. The same receiver and cap were used throughout, and the cap was screwed on with substantially the same measured torque before each test.

* Communicated by the Director.

[1] "Theory of Sound," 2d Ed., vol. 1, p. 367 (1894).

The results are summarized graphically in the accompanying figure. It will be seen that as the metallic thickness of the diaphragm was increased from 0.13 to 0.33 mm. the resonant or natural frequency followed the curve *ABC* from *A* at 970 ∞



to *C* at 1175 ∞. If the frequency had been proportional to the thickness, the graph would have been a straight line from the origin to some point such as *C*.

A reason for the departure from the simple straight-line law is found in the air-gap curve *DEFG*, which varies from 0.1 mm.

with the thinnest diaphragm to nearly 0.32 mm. with the thickest. These air-gaps were measured by means of a depth gauge, after the diaphragms were set in place. It is evident that the thin diaphragms are bowed in toward the centre by the magnetic attraction of the permanent poles. This inward bending not only distorts the diaphragm, but it also tends to make it behave partly like a stretched membrane rather than like a simple plate. The laws of vibration of a membrane and of a plate are different. The curve *ABC* indicates, however, a tendency to follow a simple straight-line law from the origin, toward the thicker diaphragms, which suffer the least bending and have the largest air-gaps.

Graph *HIJK* shows the "sensitiveness" of the receiver with the various successive diaphragms, as deduced from the diameters of the mean corresponding motional-impedance circles. These circles are reproduced in the left-hand top corner of the figure, for the japanned diaphragms only. It is known that for one and the same telephone receiver, operated at constant alternating-current strength, the sensitiveness of the apparatus is proportional to the diameter of the motional-impedance circle. It will be seen that the graph indicates a maximum of 140 ohms, near to 0.13 mm. thickness. This property depends both on the mechanics of the diaphragm and on the electromagnetics of the instrument, as influenced by the air-gap, so that the relation to diaphragm thickness is not a simple one.

Finally, the broken line *LMNP* represents the successive observed "resonant ranges" of the instrument, in cycles per second, as taken from the mean motional circles. The resonant range may be defined as the difference between the two frequencies—one on each side of the resonant frequency—at which the kinetic energy of vibration under constant alternating-current excitation falls to one-half. It may be found from the difference of the quadrantal point frequencies in the circle. Sharp resonance means a small range, and blunt resonance a large range. Theoretically, the resonant range of a simple plate diaphragm should vary inversely as the thickness;[2] so that doubling the thickness should halve the range. The graph suggests a rough approximation only to this simple theoretical relation.

It may be observed, as a matter of interest, that the depres-

[2] "Motional-Impedance Circle of the Telephone Receiver," by H. O. Taylor, *Proc. Radio Club of America*, June, 1917.

sion angles of the diameters of the various motional-impedance circles remain not far from 45 degrees throughout the series.

Conclusions.—The observations indicate that the natural frequency of a telephone receiver is not simply proportional to the diaphragm thickness—for at least one reason: that the thin diaphragms are subject to greater magnetic distortion. The observed sensitiveness passed through a maximum for this particular instrument near to the thickness of 0.23 mm. The resonant range diminished as the thickness increased.

More than fifty motional-impedance circles were measured and computed in the course of the research.

We are indebted to the Western Electric Company for the various samples of diaphragm which were used in the test, and also to Mr. H. A. Affel for his assistance and suggestions.

Packing and Plant Handling of Hazardous Chemicals. N. A. LAURY. (*Metallurgical and Chemical Engineering*, vol. xvii, No. 7, p. 407, October 1, 1917.)—Many attempts have been made to devise a safe and economical package for the transport of the convenient quantity of one or two hundred pounds of acid or other corrosive liquid, but nothing has yet been suggested that equals the standard form of wood-packed glass carboy for general use. The greatest danger in the handling of carboys is the sudden giving away of the bottom or sides of the box, due to the corrosion of the nails or weakening of the wood by acid, especially after long storage. This danger can be satisfactorily eliminated by the use of wood preservative. Untreated boxes last about two years under normal conditions. During this period the box has to be renailed three times and requires one new bottom and one new cover. Carboys treated two years ago are still in service, and very few of them have required renailing and none have had new covers or bottoms. This applies also to the standard lead carboy for the transport of hydrofluoric acid. Steel drums are used for this purpose in Europe and are said to be safer and cheaper, but they are not yet accepted for rail shipments in this country.

There is in current use a stoneware stopper and plaster-of-paris, tied down with cloth, the latter sometimes coated with tar or paraffin. If the plaster is mixed in small quantities and applied fresh, it holds so firmly that the carboy may be moved about by the stopper, but in a few days the acid loosens the grip of the plaster, and the cloth, even when treated, crumbles away. The safest stopper in use consists of a glass or stoneware plate with a tar paper, asbestos, or rubber jacket held on by a wire clip like a fruit jar.

THE FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting held Wednesday, October 17, 1917.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 17, 1917.

PRESIDENT DR. WALTON CLARK *in the Chair.*

In calling the meeting to order the Chairman announced that a number of changes, which are expected to be only temporary, had occurred in the Institute management, due to the present war. Dr. Owens, the secretary, is now with the American Expeditionary Forces in France as a major in the Signal Corps. Mr. T. R. Parrish, Science and Arts Assistant, is now lieutenant in the Signal Corps. Mr. William C. Wetherill, chairman of the Committee on Science and the Arts, and member of the Board of Managers, is at present located in Boston, Mass., in the Naval Aviation Department of the Massachusetts Institute of Technology, where he will receive his commission as lieutenant, and Mr. Theobald F. Clark, member of the Board of Managers, is now a captain in the Artillery. The Chairman further stated that Dr. George A. Hoadley is serving as Acting Secretary during the absence of Dr. Owens.

Additions to membership since last report, 13.

Mr. Louis E. Levy, chairman *pro tem.* of the Committee on Science and the Arts, reported the conditions of the work of the committee.

The President announced that the first business of the meeting would be the presentation of the Edward Longstreth Medal of Merit on recommendation of the Committee on Science and the Arts, and recognized Mr. Louis E. Levy, who, on behalf of the Committee on Science and the Arts, introduced Mr. P. Noyes Riedinger, the representative of the Hooven, Owens, Rentschler Company, of Hamilton, Ohio, who had been recommended for this award for "the development of ingenious methods used in the manufacture of the Hooven Automatic Typewriter."

The President presented the medal and accompanying certificate to Mr. Riedinger, who expressed his thanks for the distinction conferred upon his company.

The paper of the evening was then presented by Gellert Alleman, Ph.D., Professor of Chemistry, Swarthmore College, Swarthmore, Pa., entitled "Occluded Gases in Ferrous Alloys." The speaker presented a comprehensive review of previous researches and investigations on occluded gases, including the work of Graham, Bessemer, Parry, Stead, Weaver, Richards, Pursell, Brown, Boudouard, and others, with a description of some of the apparatus used by the various investigators. The lecturer then described in detail a new apparatus which he devised and has employed in his experiments. The changes in physical and chemical properties of ferrous alloys

due to the presence or absence of gases were fully described. The lecture was illustrated by high-temperature and vacuum apparatus and numerous lantern slides. In the discussion which followed the reading of the paper, Mr. Levy, Doctors Northrup and Hering, and others participated.

A vote of thanks was extended to the speaker, and the meeting then adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, October 3, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 3, 1917.

MR. LOUIS E. LEVY, *Chairman pro tem.*

The following report was presented for reconsideration and adopted:

No. 2668.—Linear Hot-Wire Anemometer. Recommended that Howard N. Potts Medals be awarded to Dr. A. E. Kennelly, for his invention of the Hot-wire Anemometer, and to Prof. Louis Vessot King, for his improved method and researches in Hot-Wire Anemometry.

The following report was presented for Final Action:

No. 2702.—Austin Organ. Recommended that the Edward Longstreth Medal of Merit be awarded to John T. Austin, of Hartford, Conn., for his invention of the "Universal Wind Chest," and its practical application in the Austin Organ.

GEO. A. HOADLEY.
Acting Secretary.

SECTIONS.

Mechanical and Engineering Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 4, 1917, at 8 o'clock, with Dr. George F. Stradling in the chair. The paper of the evening, entitled "The American Air Service," was presented by Dr. W. F. Durand, Chairman, National Advisory Committee for Aeronautics, National Research Council.

The lecturer reviewed the various steps taken in the development of the great air fleet for military use in France, and referred briefly to the equipment of the different types of machines, their chief characteristics and requirements for effective service. The development of the United States aeronuatic engine was described, with same intimation of the steps taken for its production in large quantity. The special needs of the naval aeronautic service were also discussed. The training of military aviators through the

various stages was considered, and a description was given of the manner in which such training is now being carried out at the various training camps in the United States.

The instrumental and military equipment of a modern airplane was described, including the instruments required for navigation, the machine-guns, bombs, and bomb-dropping devices. The subject was illustrated by a large collection of lantern slides.

After a brief discussion a vote of thanks was extended to the speaker and the meeting adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

Electrical Section.—A joint meeting of the Section and the Philadelphia Section, American Institute of Electrical Engineers, was held in the Hall of the Institute on Thursday evening, October 11, 1917, at 8 o'clock. Mr. W. C. L. Eglin and Mr. Nathan Hayward presided jointly.

A communication, entitled the "Propulsion of Ships," was presented by Mr. Eskil Berg, of the General Electric Company, Schenectady, N. Y.

The speaker reviewed briefly the present methods for propelling vessels, devoting considerable attention to the steam turbine as applied to marine propulsion. Geared turbines and electric drive installations were also considered, and the economical and efficient results obtained from such installations were pointed out.

The electric propelling machinery installed in some of the more recent warships was described in detail. The subject was fully illustrated by lantern slides.

After a discussion by several members and visitors the thanks of the meeting were extended to the speaker.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, October 10, 1917.)

RESIDENT.

MR. CHARLES HART, President, Delaware River Steel Company, Chester, Pa.

MR. WILLIAM F. TURNBULL, Instructor, University of Pennsylvania, Philadelphia, Pa.

NON-RESIDENT.

MR. WILLIAM H. BASSETT, Technical Superintendent, American Brass Company, Waterbury, and for mail, Cheshire, Conn.

MR. JOSEPH J. WILLIAMS, Mechanical Draftsman, Wadesville, Ind.

CHANGES OF ADDRESS.

MR. PHILIP WERNER AMRAM, 4000 Pine Street, Philadelphia, Pa.

MAJOR JOHN H. BARR, St. Nicholas Apartments, 2230 California Street, Washington, D. C.

MR. G. E. CHAMBERLAIN, 2044 Maplewood Avenue, Toledo, Ohio.

MR. FRANCIS T. CHAMBERS, 605–608 New Stock Exchange Building, 1411 Walnut Street, Philadelphia, Pa.
MR. HAROLD V. COES, 42 Forest Street, Monclair, N. J.
MR. SAMUEL H. COLLOM, 505 Abbott Building, Philadelphia, Pa.
MR. A. DE MACEDO, 5340 Magnolia Avenue, Germantown, Philadelphia, Pa.
MR. LOUIS A. FERGUSON, 1601 Wesley Avenue, Evanston, Ill.
MR. ELMER K. HILES, 568 Union Arcade Building, Pittsburgh, Pa.
MR. J. ROGERS HOLCOMB, Walnut Hill, New Castle, Del.
MR. ZAY JEFFRIES, care of Aluminum Castings Company, 2800 Harvard Avenue, Cleveland, Ohio.
MR. E. E. KELLER, 621–659 Bellevue Avenue, Detroit, Mich.
LIEUT. CHESTER LICHTENBERG, Company 2, E. R. O. T. C., Camp American University, Washington, D. C.
MR. R. L. O'DONNEL, Pennsylvania Railroad Company, 309 Broad Street Station, Philadelphia, Pa.
MR. ROBERT S. REDFIELD, Wayne, Pa.
MR. W. S. RUGG, The University Club, 4439 Grant Boulevard, Pittsburgh, Pa.
MR. I. F. STONE, 244 Madison Avenue, New York City, N. Y.
DR. L. M. TOLMAN, 6505 Harvard Avenue, Chicago, Ill.
MR. LOUIS B. WHITNEY, Alpha Portland Cement Company, 428 Oliver Building, Pittsburgh, Pa.
MR. J. D. WILLIAMSON, 69th Avenue and 11th Street, Oak Lane, Philadelphia, Pa.

NECROLOGY.

Virgil G. Bogue was born at Norfolk, N. Y., July 20, 1846, and died at sea on October 14, 1917.

His early education was obtained in his native town and at Russell's Military School, New Haven, Conn. He graduated from the Rensselaer Polytechnic Institute as a Civil Engineer in 1868. Mr. Bogue began his professional career, which covers nearly fifty years, as assistant engineer of Prospect Park, Brooklyn. From 1869 to 1879 he was assistant engineer of the Oroya Railway and manager of the Trajille Railway in Peru. He then became assistant engineer of the Northern Pacific Railway Company, and for several years supervised the construction of the railroad across the states of Idaho and Washington. In 1886 he was appointed chief engineer of the Union Pacific Railroad, and five years later opened consulting engineering offices in New York City.

Mr. Bogue was a member of the commission appointed by President Harrison to investigate the methods for improving navigaton of the Columbia River. He was consulting engineer for the Government of New Zealand, and acted in the same capacity for the Department of Public Works of New York and the Western Maryland Railroad.

From 1905 to 1909 he was chief engineer and vice-president of the Western Pacific Railway. He prepared plans for the improvement of the city of Seattle, Washington; for the Harbor of Tacoma, and for Gray's Harbor, Washington.

He was a member of numerous engineering societies and clubs. He became a member of The Franklin Institute on June 11, 1914.

Amos Peaslee Brown was born in Germantown, Philadelphia, on December 3, 1864, and died at Atlantic City, N. J., on October 9, 1917. After a general educational training he entered the University of Pennsylvania in 1882 and was graduated as a Mechanical Engineer.

From 1887 to 1889 he served as an aide on the Second Geological Survey of Pennsylvania, and in the latter year joined the staff of the University of Pennsylvania as instructor in mining and metallurgy. He received the degree of Doctor of Philosophy from the University in 1892, and was appointed professor in mineralogy and geology, which position he held until May, 1917, when he resigned on account of ill-health.

Dr. Brown was the author of numerous papers on geology, mineralogy, and palæontology, and in 1901 edited "Erni's Mineralogy." He is the author, with E. T. Reichert, of the work on "Crystallography of Hæmoglobin," in two volumes, published in 1909.

Doctor Brown was a member of the leading scientific societies of this country. He became a member of The Franklin Institute on April 25, 1890.

William Horstmann was born in 1855 and died on October 11, 1917. When a young man he was employed for a short time by the William H. Horstmann Company, the firm founded by his grandfather. He spent most of his time in recent years in travelling.

Mr. Horstmann was a member of numerous clubs and societies. He became a member of The Franklin Institute on May 14, 1881.

Edward deVeaux Morrell was born at Newport, R. I., on August 7, 1862, and died at Philadelphia on September 1, 1917.

He was graduated from the University of Pennsylvania with high honors in 1885, and the degrees of Master of Arts and Bachelor of Laws were conferred upon him in the year 1887, in which year he was also admitted to the bar.

In 1891 he was elected a member of Select Council of Philadelphia, serving for three years. He entered the National Guard of Pennsylvania as colonel of the Third Regiment, was promoted to inspector general, and later became brigadier general, commanding the First Brigade. He was elected a member of the Fifty-sixth Congress in 1900, and was three times re-elected, serving until 1907.

General Morrell became a member of The Franklin Institute on December 10, 1907.

George Smith Rider was born at Providence, R. I., on May 4, 1858, and died suddenly at Cleveland, Ohio, on September 11, 1917.

His early education, as well as his collegiate training, was received in New England, where he also began his engineering career as apprentice with the Brown & Sharpe Manufacturing Company. After a few years of travel abroad he located at Cleveland, Ohio, and obtained a position with the Warner & Swazey Company. He next became connected with

the Cummer Engine Company, where he remained until he was appointed an instructor at the University School of Cleveland.

While connected with the University School he opened a consulting engineering office, which he conducted successfully for a period of about fifteen years. Mr. Rider devoted his attention to the designing of power and industrial plants.

He was a member of the leading engineering societies, and his membership in The Franklin Institute dates from January 31, 1901.

Mr. Charles A. Catlin, 133 Hope Street, Providence, R. I.
Mr. Llewelyn T. McKee, 318 East Market Street, Bethlehem, Pa.

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PRACTICAL STRUCTURAL DESIGN, by Ernest McCullough, C. E. New York, U. P. C. Book Company, 1917. 303 pages, illustrations, 6 × 9 inches, cloth. Price, $2.50.

In the field of structural design, particularly as applied to building construction, the procedure in fixing the sizes of the component members of a structure have been reduced, relatively speaking, to a few simple theorems of statics not difficult to comprehend and apply with a limited mathematical equipment; and, with the protection of carefully drawn building laws, no very serious mistakes can be made on occasional problems of design which might strictly require an analysis beyond the powers of those whose acquaintance with the subject is thus limited.

The book is primarily intended for this class of readers—men who cannot attend evening classes. It is also intended as a text-book in such classes. The subject-matter consists of the usual problems of practice, which really constitute all but a small percentage of design operations. Being limited as to mathematical treatment, some important theorems have to be stated without formal proof. The work is divided under the following general headings: External Forces, 47 pages; Internal Forces, 29 pages; Problems in Design of Beams, 17 pages; Girders and Trusses, 34 pages; Joints and Connections, 71 pages; Graphic Statics, 34 pages; Columns and Struts, 54 pages; Index, 8 pages.

The work is very practical as well as deductive in treatment and is well adapted to the needs of evening-school students.

LUCIEN E. PIÇOLET.

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CURRENT TOPICS

An Apparatus for Separating Visible from Invisible Light. W. S. ANDREWS. (*General Electric Review*, vol. xx, No. 10, p. 817, October, 1917.)—A flux of pure invisible light is necessary for the examination of the true fluorescent colors of fluorescent compounds or for other purposes. The author has constructed a simple and inexpensive apparatus for this purpose, based on a method of separating the invisible ultra-violet rays from visible light of a mixed spectrum described by Prof. R. W. Wood in a lecture before the Royal Institution of Great Britain in 1911. The apparatus consists essentially of a suitable light source, a quartz lens, a pinhole diaphragm, and a screen mounted along an axis in the order named. A light containing a large percentage of ultra-violet radiation may be produced by a high-tension disruptive spark between iron terminals.

The operation of this instrument, which naturally must be in a darkened room, is based on the fact that the mean focus of visible light is located at measurable distance beyond the mean focus of invisible ultra-violet light, owing to the greater refrangibility of the latter over that of the former. If, therefore, the diaphragm is adjusted to bring the pinhole into the exact mean focus of ultra-violet light, the rays of the latter will pass through the pinhole and spread out again on the other side of the diaphragm. The mean focus of visibe light being at some distance beyond the pinhole, these rays will be largely intercepted by the diaphragm, and only a few of the nearly parallel rays of visible light will pass through the pinhole. In operation, if the screen is made of non-fluorescent material, there will appear on it only a small illuminated spot, but if it is coated with a fluorescent substance, such as powdered willemite, the small luminous spot will be surrounded by a disk of bright green light produced by the fluorescence of the willemite excited by the circular field of the invisible ultra-violet rays. Should it be found desirable to eliminate the spot of visible light, a small metal disk can be set up in such a position as to cast its shadow over the spot and so transform it into a dark spot, leaving the disk of green fluorescent light otherwise unimpaired.

The apparatus resembles somewhat in general form an ordinary projecting lantern, and is valuable for determining the exact fluorescent colors of various compounds. When such compounds are exposed to the direct rays of an open iron spark, their true fluorescence is marked to a greater or lesser degree by the visible light component of the spark, this being especially the case with compounds that show only a weak intrinsic fluorescence. When a compound is placed within the field of the ultra-violet rays of this *separator*, it

shows its true fluorescent color, and the passing it thus into a visually dark field and its becoming thereby illuminated produce a surprising and interesting effect.

The Spectroscopic Determination of Small Amounts of Lead in Copper. C. W. HILL and G. P. LUCKEY. (*Proceedings of the American Electrochemical Society*, October 3–6, 1917.)—A rapid method for the determination of lead in factory samples of copper depending upon spectroscopic observation has been under development by the authors. A known weight of copper is placed in a slight cavity in a lower positive graphite electrode, and a fixed or rotating carbon negative electrode is used above. A grating spectroscope serves to observe the spectrum. The time required to cause the disappearance of the bright lead line in the spectrum, or to cause its enfeeblement to a certain dimness, is measured with a stop-watch. With a carefully regulated arc, the times vary regularly with the amount of copper used and with its percentage of lead; *e.g.*, from 14 seconds with 0.2 gramme of copper containing 0.004 per cent. lead to 277 seconds with 1 gramme of copper containing 0.038 per cent. lead. The results are sufficiently reliable for practical use in the copper refinery.

The use of the arc is limited to the determination of small amounts of impurities which are volatilized at a comparatively low temperature in the presence of a metal which is not rapidly volatilized at a comparatively high temperature which gives a steady arc, the existence of strong characteristic spectrum lines being assumed. The method might be applied to metals of low boiling-point or even to salts by substituting a heating strip in place of the arc and securing the arc or spark spectrum from the vapors arising from the heating strip.

Extruded Metal. ANON. (*The Metal Industry*, vol. 15, No. 10, p. 435, October, 1917.)—Metal wire and rod made by the extrusion process is coming more and more into common use, according to the *Scovill Bulletin*. For many years wire and rod have been made by the drawing process in which the metal is pulled through dies, successively reducing its diameter or shape. Volume of production was limited at first by the time consumed in attempting to reduce the wire too much at one draft, which resulted in pulling the metal apart, and in the frequent annealings necessary to soften the wire. By the extrusion process the metal is pushed through the die while quite hot, thus overcoming at once the two limiting conditions of wire-drawing. The wire does not break because it is pushed through the die, and it does not get hard because it retains its softening temperature during the extruding. The process has been used in producing lead wire and lead pipe for a number of years. The problem of extruding lead, however, presents very few difficulties, as the softness of the lead allows it to be forced through the steel die cold.

For lead extrusion, the necessary equipment consists of a multiple plunger pump, a hydraulic accumulator, and a hydraulic press with attachments. Briefly these attachments consist of a heavy steel cylinder with a die-holding arrangement on one end, the other end being open to form a close fit to the plunger or ram of the hydraulic press. In extruding lead wire, a large piece of lead is placed within this cylinder and the press started. Lead wire will flow continuously from the hole in the die until the ram reaches the end of its stroke; it is then withdrawn for a new supply of lead. During the two strokes of the ram there occurs no break in the lead wire, the second supply of lead welding perfectly to what remains of the initial charge. In producing lead pipe, a long arbor is used, the point of which enters the die in such a way as to form a ring-shaped nozzle which determines the cross-section of the pipe.

Recognizing the possibilities of this process, experiments were made with the object of producing brass rod and wire by the extrusion process. Difficulties at once arose. It was found that to secure desired results, all the metal must be quite hot during the extruding, that hydraulic presses of great power were necessary, and that dies suitable for lead extrusion would not withstand the temperatures essential to successful results. These difficulties have, however, been overcome and a number of firms are now making brass rod by the extrusion process. A valuable feature of this process is the practicability of extruding the brass through odd-shaped dies to form certain cross-sections very expensive to obtain by other methods.

Largest Ingot Mould Ever Made. ANON. (*Mining and Scientific Press*, vol. 115, No. 15, p. 543, October 13, 1917.)—The largest ingot mould ever made has just been poured by the Bethlehem Steel Company at South Bethlehem, Pa. Its dimensions are 15 feet 7 inches high, with a mean diameter of 91½ inches, its shape being octagonal and corrugated. At its thinnest section or point of corrugation the thickness of the metal is 15 inches, and the heaviest section is 20¾ inches. A mould of this size is made so that steel can be poured into it to form ingots large enough to be reconverted into 16-inch and 18-inch guns. A steel ingot poured in this mould will weigh 300,000 pounds, and from it tubes and jackets for the large guns will be forged. Before the mould can be used large steel bands, 12 inches wide, must be shrunk around each end of the casting after it has cooled. Because of the necessity of pouring this large mould quickly, Bessemer pig-iron was melted in three large open-hearth steel furnaces and the melted iron suspended in ladles over the mould at one time. A continuous runner from the ladles was made so that the iron was thoroughly mixed before entering the mould. It took 340,000 pounds of pig-iron to pour the casting, not counting the 10,000 pounds needed later to fill up the sink-heads so as to take care of the natural shrinkage. The mould had to be left covered in the sand for a considerable time to completely cool. Two large

100-ton cranes were used to lift it from its pit and prepare it for transference to the open-hearth department, where it will be used regularly for casting ingots.

The French Official Horsepower Formula for Rating Automobile Engines. ANON. (*The Autocar*, vol. xxxix, No. 1145, p. 300, September 29, 1917.)—The question of a formula which will give some fairly approximate idea or reasonable basis of comparison of the power capacity of an internal-combustion engine has long been of interest. In England it is well known that for taxation purposes the Government adopts the R.A.C. formula, $D^2 \times N \div 2.5$, D being the cylinder diameter in inches and N the number of cylinders. The drawback to this formula is that no regard is paid to the question of the effect of varying piston stroke on the power development. According to *Cycle and Automobile Industries*, in France a new formula has been issued by the Ministry of Public Works, and is now being employed by the Service des Mines for determining the amount of annual tax payable by car owners.

The new formula is $H.P. = N \times K \times D^2 \times L \times n \div 60$; in which N is the number of cylinder; K a constant whose value is, for single cylinders 0.002, for two cylinders 0.00017, for four cylinders 0.00015, and for more than four cylinders 0.00013; D the bore in centimetres, L the stroke in centimetres, and n the number of revolutions for the maximum speed of the car on the level. While on the basis of equal bore and stroke the French formula gives a lower rating in the case of two- and four-cylinder engines than the British, the introduction of the stroke in the formula has a marked upward effect on the horsepower rating of the engines. It is apparent, however, that one of the drawbacks of the new French formula will be the problem of deciding as to the number of engine revolutions to be taken into account, the maximum speed of the car depending on many variable quantities.

Suggested Reforms in Some Chemical Terms. C. HERING. (*Proceedings of the American Electrochemical Society*, October 3–6, 1917.)—Physical chemistry has done so much for the benefit of chemistry that chemists should in return recognize, readjust, and redefine some of their terms to bring about a better concordance with physical chemistry and a better consistency in pure chemistry. The author's purpose is to point out some of these deficiencies and to suggest a few reforms which would help to systematize these terms, make them more consistent with each other and with modern developments, and to simplify the conceptions involved. The scope of the discussion is limited to that branch of chemistry in which electrons are involved, no attempt being made to embrace organic chemistry and the chemistry of non-electrolytes.

A number of recommendations are made. These are: A more precise distinction should be made between different kinds of *bonds*.

The term *valence* should be more strictly defined, and negative and zero valences should be included. A proposed practical unit for measuring electrons should be used. The *ionized* state should be considered as differing in kind from either the *free* or the *combined* state. *Reduction* should include all and only cases of reductions in valence, and *oxidation* all and only cases of an increase in valence, hence the new term *adduction*. The significance of the gaining and losing of electrons should be more clearly understood; the sign of electrode potentials is then more easily understood. As sometimes stated, Faraday's law is not a universal one; it is a corollary to a more basic one.

Cooling Underground Cables. ANON. (*Electrical World*, vol. 70, No. 15, p. 720, October 13, 1917.)—During the last summer a central station company in the Middle West which operates a rather extensive underground cable system made several experiments with the hope of discovering an effective means of reducing the operating temperature of its lead-covered cables. While none of the experiments developed any particularly successful method, the results of the experiments may be of some value to other companies contemplating similar tests. The first experiment, in which an attempt was made to cool the manholes and conduits by placing ice in the holes, was a failure. Each day for three days 200 pounds of ice was placed in each of three manholes. The centre manhole was on the top of a hill, and at that point a recording thermometer was stationed. The ice seemed to have no effect on the temperature, so the quantity of ice in each manhole was doubled. This did not affect the temperature, and the experiment was discontinued.

A forge blower fan was then placed in the previously mentioned middle manhole and was connected to a 6-inch sewer tile vent, which extended a distance of about 10 feet to the inside of the street curb. This fan was kept running 24 hours a day, exhausting approximately 300 cubic feet of air per minute. Although the fan exhausted a considerable quantity of warm air, the recording thermometers did not show any appreciable effect on the temperature of the manhole.

Following these experiments, it was decided to try cooling the cables by water. It was found that with a stream of water at 82° F., flowing at the rate of one gallon per minute, the temperature at the discharge end, which was 251 feet distant, was 108° F. On account of the condition of the cable in the district where this experiment was made, further investigation was considered unwise. It was therefore impossible to follow this apparently most successful investigation to a point that would give definite results.

Cracking Nuts by Centrifugal Force. ANON. (*Scientific American*, vol. cxvii, No. 13, p. 232, September 29, 1917.)—Palm oil and palm-nut kernels to the value of about $7,000,000 are imported annually by the United States, the bulk of which come from

the west coast of Africa, small quantities from Mexico, and recently it has been discovered that palm nuts are also to be found in Central America. Prompted by the European war's effect upon shipments from Africa, and the difficulty experienced in developing business in Mexico on account of internal troubles, a company with headquarters in Los Angeles invaded Central America and is making preparations to develop the industry on a very extensive basis. This company started with about fifteen tons of machinery designed especially for the purpose.

The machine is a particularly clever device, in that it cracks nuts solely by centrifugal force. It is shaped somewhat like a drum and measures six feet in diameter. It stands, when the top feed and the bottom discharge have been added, nearly seven feet high, and weighs approximately 6000 pounds, the main casting alone weighing 3400 pounds. The nuts are conveyed in a steady stream to the hopper at the top, and from the hopper they drop into a fast-revolving drum-wheel, which throws them with great force against a continuous stationary belt of breaker-blocks lining the inside surface of the main, drum-shaped casting. A pressure of about 1800 pounds is required to crack them, as the nuts have an extremely hard shell, about a half inch thick. The drum-wheel, turning on a perpendicular-set axle, is speeded to 800 revolutions per minute and hurls the nuts on a tangent a distance of but two feet. This force is sufficient to break the shells into several pieces and release the kernels. Deflected by the downward-sloping surface of the breaker-blocks, the kernels and hulls drop toward the bottom of the machine, where they enter a discharge pipe and are separated from each other by a system of blowers. The machine has a capacity of about ten tons of nuts per hour.

The difficulty experienced heretofore in preparing these nuts for the market was the matter of cracking the hard inner shell. In Mexico this work is ordinarily done by hand, and is tedious and slow. The machine solves the problem very advantageously because of its greater capacity, and in that, by cracking the nuts by centrifugal force, the kernels, for the most part, remain whole and do not lose any of their oil. Preparations are also being made for the removal of the outer hull by machinery designed somewhat on the same principle as the large cracker. The only hand work will be the gathering, and this is usually done by raking the nuts into piles after they have fallen from the tree, or by cutting the bunches from the trees before they begin to fall.

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